

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

**NASA TECHNICAL  
MEMORANDUM**

NASA TM X-73607

NASA TM X-73607

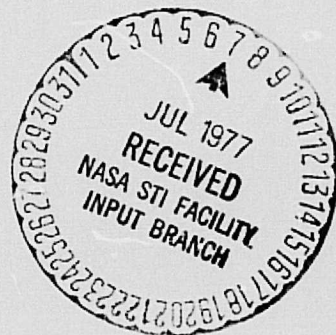
(NASA-TM-X-73607) A COMPUTERIZED TRAFFIC  
CONTROL ALGORITHM TO DETERMINE OPTIMAL  
TRAFFIC SIGNAL SETTINGS Ph.D. Thesis -  
Toledo Univ. (NASA) 255 p HC A12/MF A01

N77-27035

Unclas  
CSCL 13F G3/85 31867

A COMPUTERIZED TRAFFIC CONTROL ALGORITHM TO  
DETERMINE OPTIMAL TRAFFIC SIGNAL SETTINGS

by Kurt Seldner  
Lewis Research Center  
Cleveland, Ohio 44135



1. Report No. <b>NASA TM X-73607</b>	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle <b>A COMPUTERIZED TRAFFIC CONTROL ALGORITHM TO DETERMINE OPTIMAL TRAFFIC SIGNAL SETTINGS</b>		5. Report Date	
		6. Performing Organization Code	
7. Author(s) <b>Kurt Seldner</b>		8. Performing Organization Report No. <b>E-9084</b>	
		10. Work Unit No.	
9. Performing Organization Name and Address <b>National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135</b>		11. Contract or Grant No.	
		13. Type of Report and Period Covered <b>Technical Memorandum</b>	
12. Sponsoring Agency Name and Address <b>National Aeronautics and Space Administration Washington, D.C. 20546</b>		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract <p>The increase in automobile traffic on urban streets compels the traffic engineer to consider a computerized traffic control system. The benefit that can be derived from an effective control system justifies the expense in planning and implementing an efficient system. A comprehensive survey into traffic control methods indicates that little effort has been devoted to control the traffic signals for a large traffic network. A control algorithm was developed to optimally control the traffic signals at each intersection using a discrete time traffic model applicable to heavy or peak traffic. Off-line optimization procedures are applied to compute the cycle splits required to minimize the lengths of the vehicle queues and delay at each intersection. The theory was applied to an extensive traffic network in Toledo, Ohio. The results obtained with the derived optimal settings and the present control settings are presented for comparison.</p>			
17. Key Words (Suggested by Author(s)) <b>Optimal control Optimization Traffic theory</b>		18. Distribution Statement <b>Unclassified - unlimited STAR Category</b>	
19. Security Classif. (of this report) <b>Unclassified</b>	20. Security Classif. (of this page) <b>Unclassified</b>	21. No. of Pages <b>253</b>	22. Price*

\* For sale by the National Technical Information Service, Springfield, Virginia 22161

A COMPUTERIZED TRAFFIC CONTROL ALGORITHM TO DETERMINE  
OPTIMAL TRAFFIC SIGNAL SETTINGS

by

Kurt Seldner

Submitted in partial fulfillment  
of the requirements of the  
Doctor of Philosophy Degree  
University of Toledo  
March 1977

Certified by:

\_\_\_\_\_  
Advisor and Co-Chairman of Systems Committee

Certified by:

\_\_\_\_\_  
Advisor and Co-Chairman of Systems Committee

Accepted by:

\_\_\_\_\_  
Dean, Graduate School

An Abstract of  
A COMPUTERIZED TRAFFIC CONTROL ALGORITHM TO DETERMINE  
OPTIMAL TRAFFIC SIGNAL SETTINGS

K. Seldner

Submitted in partial fulfillment  
of the requirements of the  
Doctor of Philosophy Degree

The University of Toledo  
March 1977

The increase in automobile traffic on urban streets compels the traffic engineer to consider a computerized traffic control system. The benefit that can be derived from an effective control system justifies the expense in planning and implementing an efficient system. A comprehensive survey into traffic control methods indicates that little effort has been devoted to control the traffic signals for a large traffic network. A control algorithm was developed to optimally control the traffic signals at each intersection using a discrete time traffic model applicable to heavy or peak traffic. Off-line optimization procedures are applied to compute the cycle splits required to minimize the lengths of the vehicle queues and delay at each intersection. The theory was applied to an extensive traffic network in Toledo, Ohio. The results obtained with the derived optimal settings and the present control settings are presented for comparison.

## ABSTRACT

The increase in automobile traffic on urban streets compels the traffic engineer to consider a computerized traffic control system. The benefit that can be derived from an effective control system justifies the expense in planning and implementing an efficient system. A comprehensive survey into traffic control methods indicates that little effort has been devoted to control the traffic signals for a large traffic network. A control algorithm was developed to optimally control the traffic signals at each intersection using a discrete time traffic model applicable to heavy or peak traffic. Off-line optimization procedures are applied to compute the cycle splits required to minimize the lengths of the vehicle queues and delay at each intersection. The theory was applied to an extensive traffic network in Toledo, Ohio. The results obtained with the derived optimal settings and the present control settings are presented for comparison.

## ACKNOWLEDGMENTS

In the preparation of this dissertation, several persons have contributed to make this effort a reality and have supported me during the course of this research. I wish to thank my advisory committee co-chairmen Dr. Leininger and Dr. Colony for their continual guidance, encouragement, and assistance. Their support and advice was greatly appreciated.

I want to recognize also the assistance provided by Dr. Muckenhirn and Prof. Hansell, who along with Dr. Leininger and Dr. Colony have served on my dissertation committee.

Mr. C. E. Riser, Commissioner of the Division of Traffic Engineering has generously provided traffic drawings, traffic data, and consultation for this research. I want to acknowledge his support for without his help this effort would have been more difficult.

I would like to acknowledge the support of the training committee of NASA Lewis Research Center for financial assistance, computing time, and the preparation of this manuscript. The assistance and support provided by Miss Gertrude Collins is greatly appreciated.

# TABLE OF CONTENTS

TITLE	Page
	i
ABSTRACT	ii
ACKNOWLEDGMENTS	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
CHAPTER I. INTRODUCTION	1
1.1 Definition of Problem	2
1.2 Summary of Chapters	3
CHAPTER II. TRAFFIC THEORY	5
2.1 Lighthill-Whitham Theory	6
2.2 Pacey Diffusion Theory	9
2.3 Robertson Recurrence Relationship	11
2.4 Car-Following Model	14
2.5 Conclusions	15
CHAPTER III. TRAFFIC CONTROL SYSTEMS	16
3.1 Measurement of Traffic Data	16
3.2 Traffic Control Concepts	17
3.3 Progression Control Systems	18
3.3.1 Bandwidth Techniques	20
3.3.2 MITROP Model	21
3.3.3 RRL Combination Method	21
3.3.4 TRANSYT Model	24
3.3.5 SIGOP Model	25
3.3.6 Application of Optimal Control Theory to Traffic Control	26
3.4 Conclusions	26
CHAPTER IV. TRAFFIC CONTROL MODELING	28
4.1 Traffic Control Requirements	28
4.2 General Traffic Models	31
4.3 Proposed Traffic Model	33
4.3.1 Description of Modeling Approach	35
CHAPTER V. OPTIMIZATION TECHNIQUES	44
CHAPTER VI. RESULTS OF PROPOSED TRAFFIC CONTROL ALGORITHM	48
6.1 Results of Two Intersection Model - Unconstrained Links	51
6.1.1 Constrained Links	65
6.2 Optimization Procedure	70
6.3 Conclusions	77



	Page
CHAPTER VII. SIMULATION RESULTS FOR TRAFFIC NETWORKS	79
7.1 Results for Section I	80
7.2 Results for Section II	132
CHAPTER VIII. CONCLUSIONS AND AREAS FOR FURTHER STUDY	184
APPENDIXES	
A - DEFINITIONS OF TRAFFIC TERMINOLOGY	188
B - LISTING OF COMPUTER PROGRAMS - TWO INTERSECTION MODEL	190
C - LISTING OF COMPUTER PROGRAMS - SECTION I	201
D - LISTING OF COMPUTER PROGRAMS - SECTION II	222
BIBLIOGRAPHY	243

## LIST OF FIGURES

Figure		Page
2-1	Fundamental diagram of traffic.	7
2-2	Robertson recurrence relationship.	13
3-1	Time-space diagram.	19
3-2	RRL combination method.	22
4-1	Traffic control system.	30
6-1	Byrne-Dorr-Secor traffic network.	52
6-2	Traffic signal timing plan - intersections 478, 497.	55
6-3	Dissipation of vehicle queues - Byrne-Dorr-Secor Unconstrained links - 7-9 a.m.	57
6-4	Dissipation of vehicle queues - Byrne-Dorr-Secor Unconstrained links - 11-1 p.m.	61
6-5	Dissipation of vehicle queues - Byrne-Dorr-Secor Unconstrained links - 3-6 p.m.	66
6-6	Dissipation of vehicle queues - Byrne-Dorr-Secor Constrained links - 3-6 p.m.	72
7-1	Traffic network - Section I.	81
7-2	Identification of intersections and queues - Section I.	82
7-3	Signal phasing diagrams - Section I.	88
7-4	Timing plan for traffic signals - Section I.	100
7-5	Dissipation of vehicle queues - Section I - 7-9 a.m.	103
7-6	Dissipation of vehicle queues - Section I - 11-1 p.m.	114
7-7	Dissipation of vehicle queues - Section I - 3-6 p.m.	123
7-8	Traffic network - Section II.	133
7-9	Identification of intersections and queues - Section II	134
7-10	Signal phasing diagrams - Section II	140
7-11	Timing plan for traffic signals - Section II	151
7-12	Dissipation of vehicle queues - Section II - 7-9 a.m.	154

Figure		Page
7-13	Dissipation of vehicle queues - Section II - 11-1 p.m.	164
7-14	Dissipation of vehicle queues - Section II - 3-6 p.m.	174

## LIST OF TABLES

Table		Page
6-1	Optimal Control Settings for Intersections 478, 497 Unconstrained Links	54
6-2	Optimal Control Settings for Intersections 478, 497 Constrained Links	71
7-1	Control Settings - Section I	85
7-2	Control Settings - Section II	137

## CHAPTER I. INTRODUCTION

The trend towards suburban living during the past few decades has contributed to the large increase in automobile traffic. The lack of convenient public transportation makes the automobile a necessity, rather than a luxury, to transport people to offices, factories, and shopping areas. As a result of this increased traffic, severe congestion is often experienced during peak hours on freeways and access streets. Traffic control studies have been directed towards improving freeway traffic. However, less effort has been devoted to devising control techniques of vehicular traffic for urban streets with signalized intersections. This task requires the computation of appropriate traffic signal settings and offsets between intersections to minimize the delay and travel time for vehicles.

The optimal control of large traffic networks is a difficult and costly effort. However, in view of the many benefits that can be expected from an optimized traffic network, the time and expense involved in planning and implementing an effective control system are justifiable. The benefits will be reduced waiting time at intersections, improved fuel economy and reduced traffic accidents. Better use of existing roadways can also be achieved.

Control of traffic signals has been studied in the U.S., Canada, England, and Japan. Traffic engineers are cognizant that future plans must include a computerized traffic control system to cope with the anticipated increase in vehicular traffic. With high fuel costs, the

ultimate goal must be to reduce the idle time at intersections and minimize or eliminate traffic congestion. Several large cities within the U.S. are using optimized traffic control systems. Outside the U.S., operational systems have been installed in Toronto, London, and Tokyo. These control systems are primarily for highly congested business areas and, in some cases, for one-directional flow.

A thorough literature search was performed on prior research in traffic signal theory in the U.S. and abroad. The research indicates that a major effort has been devoted to time-space analysis where traffic signals are synchronized along a roadway. A comparatively small effort has been expended in applying modern control and optimization procedures to the solution of large traffic networks. With the availability of high speed digital computers, these concepts can now be applied to optimally derive the traffic signal settings required to minimize the delay and travel time of the vehicles.

### 1.1 Definition of Problem

The goal of this dissertation research is to develop a traffic control algorithm to compute the optimal signal settings to minimize vehicular queues throughout a large traffic network. The intent of this effort is to apply modern control and optimization concepts to solve this traffic problem. Representative models of the traffic networks using linear discrete time difference equations were formulated. The models are developed in a generalized form and describe the behavior of the vehicle platoons as they travel through the network. An efficient optimization procedure was selected to compute the control variables. Optimal phasing and timing plans were generated from the models for

three specified time intervals. A technique used to clear selected queues and eliminate internal congestion was demonstrated for two critical intersections.

## 1.2 Summary of Chapters

The dissertation is divided into two sections. The first part is a discussion of the existing traffic theory and control systems. The second portion covers the research on the proposed traffic control algorithm, optimization procedure, and its application and results for two traffic models. The principles of basic traffic theory and methods to describe platoon behavior and dispersion are reviewed in Chapter II. The first portion of this chapter considers macroscopic models such as Lighthill-Whitham theory, Pacey diffusion theory and Robertson Recurrence Relationship. These methods use the traffic variables (flow, average speed, and density) to model traffic behavior. The second part discusses microscopic or car-following models.

Several traffic control systems presently operational are reviewed in Chapter III. The basic principles of these traffic control systems are briefly discussed. The application of modern control theory to the solution of traffic control problems is presented in Chapter IV. The proposed traffic control algorithm and modeling techniques for single and multiple intersections are presented. An optimization procedure to derive the optimal control settings is discussed in Chapter V.

The proposed traffic theory developed in Chapter IV was applied to a critical two intersection problem. The purpose of this analysis was to clear internal queues and prevent congestion between intersections. State weighting was used to increase the priority for these critical queues. The results for constrained and unconstrained links are pre-

sented in Chapter VI.

Two large traffic models were formulated by using the proposed traffic theory. Optimal traffic signal settings were derived for three time intervals. Results showing the behavior of the vehicle queues, phasing and timing plans are given in Chapter VII.

Chapter VIII presents a summary of results and proposes areas for further study.



## CHAPTER II. TRAFFIC THEORY

The two concepts used in modeling traffic behavior are macroscopic and microscopic models. The selection of the type of model depends on the ultimate objectives of the analysis. If the model should consider traffic quantities such as flow, density, and average speed, then a macroscopic model adequately describes the behavior of the vehicle platoons. The definition of the above quantities is given in appendix A.

The macroscopic or continuum model is based on physical analogies such as kinematic waves, compressible flow theory, heat flow, and energy momentum concepts. Generally accepted techniques are the continuum theory by Lighthill-Whitham (11,37), Pacey's diffusion theory (16,37), and Robertson's recurrence relationship (36,37). The basic element of macroscopic models is the conservation of vehicles balance.

The three methods (Lighthill-Whitham, Pacey, and Robertson) require knowledge of the traffic flow ( $q$ ) in increments of time at the intersection and at various points along the link. The Lighthill-Whitham theory requires a relation between average speed, flow, and density within the link. The Pacey diffusion theory requires the position, speed, and acceleration of each vehicle in the platoon while it is traveling in the specified link. The Robertson recurrence relation requires a valid value for a smoothing factor. The TRANSYT model, discussed in Chapter III, is based on the Robertson recurrence relationship.

Whenever the behavior of each individual vehicle must be accurately described, a microscopic model can be used. The microscopic viewpoint

treats the behavior of a driver when following other vehicles in a single lane of traffic. The simplest microscopic models are linear and nonlinear car following models where the behavior of the individual driver is influenced by the preceding vehicle (5,11,12,13,18).

## 2.1 Lighthill-Whitham Theory

Lighthill-Whitham use continuum theory or kinematic wave theory to describe bottlenecks and disturbances caused by traffic signals. The theory can predict variations in average speed ( $\mu$ ), density ( $\rho$ ), and flow ( $q$ ) in a platoon of vehicles (11,37) and is based on two principles:

- (i) The flow ( $q$ ) can be expressed by the continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial q}{\partial X} = 0 \quad (2-1)$$

- (ii) The existence of an equation of state that relates the flow ( $q$ ) and density ( $\rho$ )

$$q = \rho \cdot \mu \quad \text{for uniform flow} \quad (2-2)$$

Substituting equation (2-2) into equation (2-1)

$$\frac{\partial \rho}{\partial t} + \mu \cdot \frac{\partial \rho}{\partial X} = 0 \quad (2-3)$$

where

$\mu$  speed of disturbance (miles/hr)

$X$  distance (miles)

Solving equation (2-3) yields

$$\rho = a(X - \mu t) \quad (2-4)$$

where  $a$  is an arbitrary constant. Equation (2-4) indicates that changes in density ( $\rho$ ) can propagate along a platoon of vehicles at a constant disturbance speed ( $\mu$ ). The speed of these waves is defined by

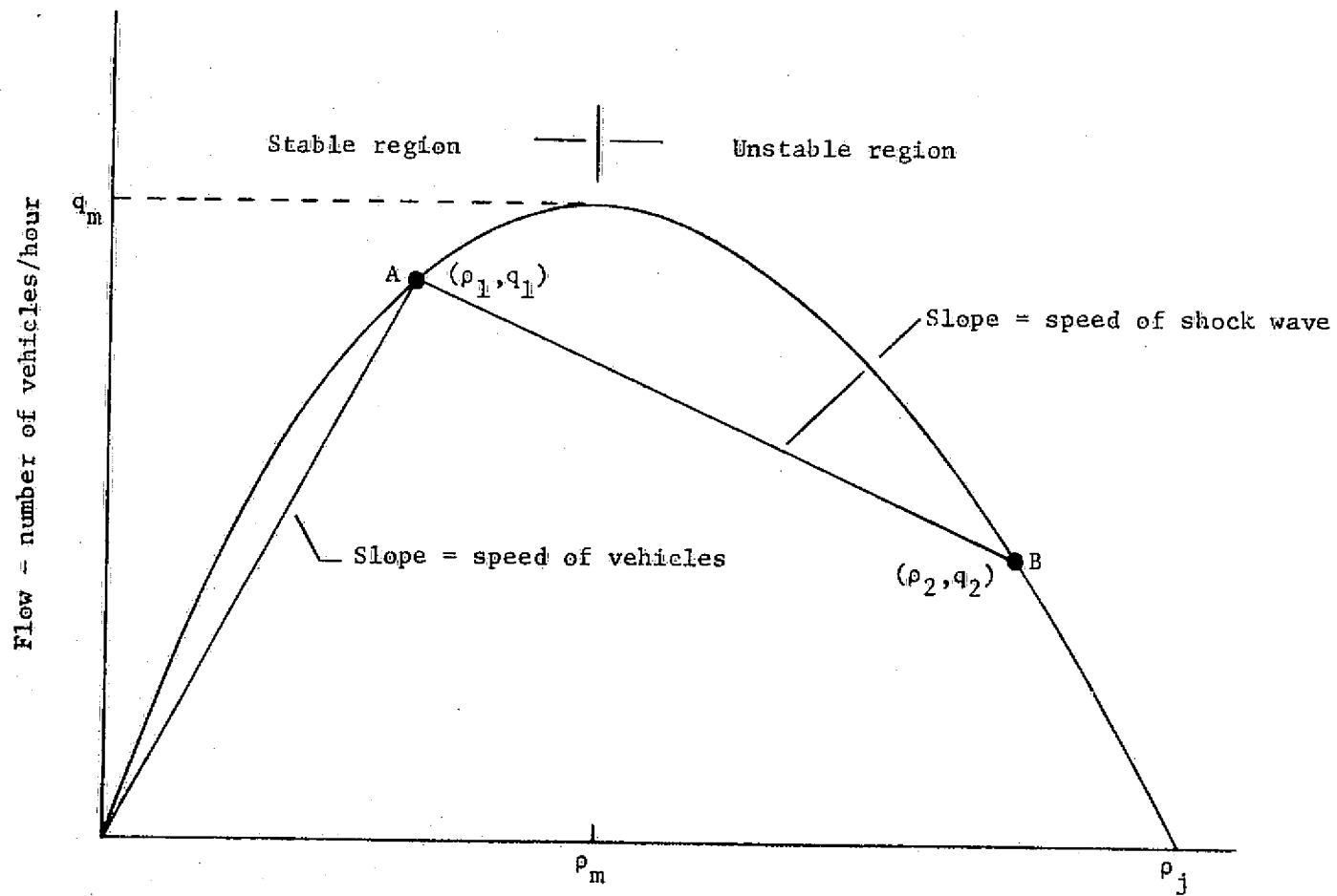


Figure 2-1. - Fundamental diagram of road traffic.

the slope of the chord linking the two points A and B (Fig. 2-1). The speed disturbances propagate opposite to the direction of the stream of vehicles.

Seddon (37) states that kinematic waves do not disperse as continuous waves, but suffer a change in form due to the dependence of the wave speed ( $\mu$ ) on the flow ( $q$ ) carried by the kinematic waves. These waves may develop discontinuities since faster waves with higher flow ( $q$ ) will overtake slower waves. Lighthill-Whitham described these waves as shock waves. The existence and speed of these shock waves can be determined directly from the flow-density relation (Fig. 2-1). The location of the shock wave and the regions of congestion can be observed from the figure (33). To illustrate, assume that an incident occurs in a link. Let point A represent the free-flowing and high flow condition immediately upstream of the incident and let point B represent the condition downstream of the incident. At point B, the traffic condition is low volume and congestion. The velocity of the shock wave is computed as:

$$\mu = (q_2 - q_1) / (\rho_2 - \rho_1) \quad (2-5)$$

the slope of the chord joining the points A and B.

Haight (17) identifies Fig. 2-1 as the "fundamental diagram of roadway traffic." The curve can be derived from the speed-density relation and expression (2-2). The speed-density relation is usually obtained experimentally with regression techniques applied to obtain a closed form expression. The shape of the curve depends on weather and roadway conditions. The figure presents factual information concerning the characteristics of the roadway, where

Capacity ( $q_m$ ) is the maximum flow ( $q$ ) that can be accommodated in a link.

$\rho_m$  is the density ( $\rho$ ) for maximum flow ( $q_m$ ).

$\rho_j$  is the jam density. The flow ( $q$ ) is reduced to zero and congestion will occur.

The region to the left of  $\rho_m$  defines the stable region where traffic flow can move at a rate determined by the flow ( $q$ ) and the density ( $\rho$ ). For example, if roadway operation can be described by point A, then the average speed of the vehicles is obtained by the slope of the chord connecting the origin and point A. For densities above  $\rho_m$  (right of capacity), the traffic flow becomes unstable and a "stop-go" driving condition will be experienced. Finally, at density  $\rho_j$  (jam condition), the flow will be reduced to zero and congestion will occur. It is recognized that a high flow in the link will reduce the average speed of the vehicles, whereas fewer vehicles implies a higher average velocity.

## 2.2 Pacey Diffusion Theory (16,37)

The Pacey diffusion theory assumes that changes in the vehicle platoon released by a traffic signal arise from the differences in speed among vehicles in the platoon. The theory assumes no hindrance to overtaking other vehicles and all vehicles proceed with a constant but unique velocity regardless of the number or distribution of vehicles in the section. Pacey assumed that if the distribution of the velocities of vehicles is normal, it is then possible to evaluate the distribution of the travel times between two positions in the link. Although the Pacey model of platoon behavior is extremely simplified, experimental

results indicate that the model predicts traffic behavior quite accurately (16).

Pacey assumes that each vehicle in a platoon moves with speed  $V$  such that

(i) The probability that the speed of any vehicles lies between  $V, V + dV$  is:

$$f(V)dV = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} \exp\left[-\frac{1}{2} (V - m)^2/\sigma^2\right] dV \quad (2-6)$$

i.e., the vehicle speeds are normally distributed with mean  $m$  and variance  $\sigma^2$ .

(ii) The speed  $V$  of any vehicle is unchanged as the vehicle moves along the link.

Condition (i) states that the speed of any vehicle in the platoon is independent of its position within the platoon. Condition (ii) assumes no interaction between vehicles such that a faster vehicle can overtake a slower vehicle without hindrance.

Grace and Potts (16) discuss the property of the Pacey model that permits diffusion to be described by a one-dimensional diffusion equation satisfied by a function related to traffic density. It can be shown (16) that the diffusion equation can be derived by assuming an initial traffic density. The probability function for density is:

$$\rho(X,t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} g(X,t) \exp\left[-\frac{1}{2} (V - m)^2/\sigma^2\right] dV \quad (2-7)$$

A change of variable results in

$$K(X,\tau) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} g[m(X - 2\beta z\sqrt{\tau})] \exp(-z^2) dz \quad (2-8)$$

where

$$z = (V - m) / \sqrt{2} \sigma$$

$$X = (X/m) - t$$

$$\tau = t^2/2$$

$$\beta = \sigma/m$$

$$K(X, \tau) = \rho(X, t)_{\tau}$$

The above equation is a solution to the one-dimensional diffusion equation:

$$\frac{\partial K}{\partial \tau} = \beta^2 \frac{\partial^2 K}{\partial X^2} \quad (2-9)$$

The diffusion equation points to the relation between the traffic parameters  $m$  and  $\sigma$  which describe the speed distribution of the individual vehicles. The diffusion constant  $\beta$  gives the rate at which the platoon diffuses and increases in length. If the vehicles travel at the same velocity  $V$ , then the standard deviation is zero and no diffusion takes place within the platoon. As the spread between the vehicle speeds increase, the diffusion constant also increases. Although flow is more commonly used since it can be measured more easily, the Pacey diffusion theory uses density. Density must be estimated unless the assumption of uniform flow is valid.

### 2.3 Robertson Recurrence Relationship

The Robertson recurrence relationship was used to predict platoon behavior for the TRANSYT method. The method employs the recurrence relation (37):

$$q_2(i + t) = Fq_1(t) + (1 - F)q_2(i + t - 1) \quad (2-10)$$

where

$q_2(i)$  derived flow in the  $i^{\text{th}}$  time interval of the predicted platoon  
at a point along the link

$q_1(i)$  flow in the  $i^{\text{th}}$  time interval of the initial platoon at the  
entrance to the intersection

$t$  0.8 times the average travel time over the distance for which  
the platoon dispersion is being calculated - usually  $1/50$   
of the cycle time

$F$  smoothing factor

Solving equation (2-10) recursively, a derived flow pattern can be  
obtained for all intervals of a cycle. The process can be illustrated  
by an example (37). Consider uniform input flow pattern at the start  
of a link. Assume the following quantities.

$$\text{Cycle time} = 75 \text{ sec} = 50 \text{ units}$$

$$\text{Travel time} = 15 \text{ sec} = 10 \text{ units}$$

$$F = 0.2$$

$$\begin{aligned} q_1(i) &= 1.0 & 0 \leq i \leq 25 \\ &= 0 & i > 25 \end{aligned}$$

Using the recursive equation (2-10)

First interval  $i = 1$

$$\begin{aligned} q_2(9) &= Fq_1(1) + (1 - F)q_2(8) \\ &= Fq_1(1) \\ &= 0.20 \end{aligned}$$

Second interval  $i = 2$

$$\begin{aligned} q_2(10) &= Fq_1(2) + (1 - F)q_2(9) \\ &= Fq_1(2) + (1 - F)Fq_1(1) \\ &= 0.36 \end{aligned}$$



Third interval  $i = 3$

$$\begin{aligned} q_2(11) &= Fq_1(3) + (1 - F)q_2(10) \\ &= 0.488 \end{aligned}$$

Fourth interval  $i = 4$

$$\begin{aligned} q_2(12) &= Fq_1(4) + (1 - F)q_2(11) \\ &= 0.5904 \end{aligned}$$

This process is continued until the flow  $q(i + t)$  approaches zero, which is the termination of the cycle. The results yield a histogram of flow within the link as a function of cycle interval. The results of the example are presented in figure 2-2. The accuracy of the model depends on a representative value for the smoothing factor  $F$ . This value is usually obtained experimentally so that a good fit is derived for the predicted flow pattern. The  $F$  value can vary depending upon site factors such as road, parking, and traffic conditions (37).

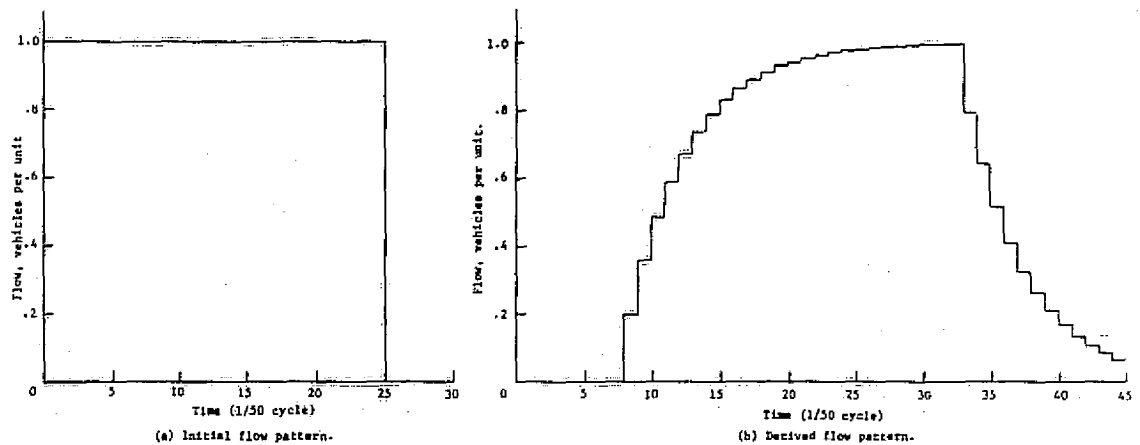


Figure 2.2. - Robertson recurrence relationship.

The Robertson recurrence relation and the Pacey diffusion method are identical, except that the former uses a geometric distribution whereas the latter method employs a transformed normal distribution. These techniques are superior to the Lighthill-Whitham continuum theory since it is difficult to establish an accurate flow-density relation.

#### 2.4 Car-Following Model

A microscopic model that has been investigated extensively is the car-following model (5,11,12,13,18), where the behavior of the individual driver is considered when following vehicles in a single lane of traffic. The model is applicable to single lane traffic with no passing and assumes that each driver reacts to a stimulus from the preceding vehicle. The analysis assumes no driver interaction and is valid only for dense traffic flow.

The basic differential equation that governs the process expresses the idea that each driver responds to a stimulus according to the relation:

$$(\text{Response})_{t+T} = \text{Sensitivity} \cdot \text{Stimulus}$$

where the response could be acceleration. Stimulus is a function of the position of the vehicle and  $T$  is the reaction time. Experimental studies indicate a high correlation between the acceleration and speed of each individual driver with that of the leading vehicle. Usually a reaction time of about 1 second exists between the leading and trailing drivers.

The differential equation of the linear car-following model is:

$$\ddot{X}_{n+1}(t + T) = \lambda[\dot{X}_n(t) - \dot{X}_{n+1}(t)] \quad (2-11)$$

where  $n$  denotes the position of the vehicle,  $X_n$  is the position of

the  $n^{\text{th}}$  vehicle,  $\lambda$  is a sensitivity constant, and  $T$  is the reaction time.

The linear car-following models are usually restricted to small disturbances about a nominal operating point. The model does not accurately describe the transitions from a steady state value which require large changes of speed and spacing (11). A difficulty that could be encountered when establishing the model is the determination of a valid sensitivity constant  $\lambda$ . To overcome some of the problems, the sensitivity constant can be modified, using the speed of the follower and the spacing between the driver and leader.

The car-following models can also be used to study the stability of traffic flow. The solution of the model differential equation shows that the stability depends on the value  $\lambda \cdot T$  (11,12). If perturbations are introduced into the stream of vehicles, increasing oscillations can occur in the distance separating the two vehicles. Overreaction by drivers and large reaction times can cause shock waves and instability.

## 2.5 Conclusions

Some principles of traffic theory and methods to describe the behavior of vehicle platoons have been presented. Both macroscopic and microscopic models were discussed. The former method uses the traffic variables - flow, average speed, and density - to describe platoon behavior. The microscopic or car-following model treats the behavior of the individual driver when following other vehicles. The selection of the type of model depends upon the requirements and goal of the traffic control system.

### CHAPTER III. TRAFFIC CONTROL SYSTEMS

The proper adjustment of traffic signals within a network determines the behavior of the traffic flow and the degree of congestion that could be experienced along the network links. Two types of traffic control systems can be considered: (1) on-line control where the control variables are altered in response to varying traffic conditions and (2) off-line control where an optimal traffic signal timing plan must be established from known traffic flow measurements. Both methods require presence detectors at the input to each link. However, for on-line control a digital computer must up-date the magnitudes of the control variables. For large traffic networks and complex traffic models, the computation time for optimization can be extensive enough to cause a large lag between actual and implemented traffic conditions. The disadvantage of off-line control is that traffic signals are not readjusted for randomly varying traffic conditions but are held constant over a specified time interval. Most traffic control systems, due to their complexity, are off-line techniques. The proposed traffic control algorithm uses an off-line optimization procedure and provides signal timing plans.

#### 3.1 Measurement of Traffic Data

Effective on-line control of traffic signals requires continuous knowledge of the traffic conditions. Presence detectors can be used to determine the flow ( $q$ ) to the network links. Several techniques are available for collecting and processing traffic data. Among these are manual counting, photographic methods, and electronic sensors. The most

popular technique is the use of an inductance loop, where several turns of wire are embedded in the pavement. A high frequency source is required for excitation to generate a magnetic field. Whenever a vehicle passes over the magnetic loop, the inductance change is monitored by a detector which generates an output whenever a threshold level is exceeded. This information is used by the data processor and converted to usable traffic flow information. The vehicle speed can be estimated from the occupancy data and an estimate of vehicle length. Density information can be approximated from a conservation of vehicles balance (33). Alternate methods, such as estimation theory, are available to approximate the density of the vehicles (14,24,31). Using Kalman filter theory, computations were performed on actual measurements for the Lincoln Tunnel of New York City (14). The results indicate good agreement between measured and estimated values.

### 3.2 Traffic Control Concepts

The traffic network can be represented as a collection of intersections and links. An accurate model that describes the behavior of the platoons as the vehicles move through the network must be formulated. A traffic control algorithm can then be developed to compute the optimal traffic signal settings to minimize selected traffic variables. However, the number of usable control variables for the traffic control system is limited. Specific controls include signal cycle time, signal split and offset between traffic signals. The input or state variables for the traffic model can be vehicle flow or average queue length. The ultimate objective of an effective traffic control system is minimum delay and travel time for the vehicles throughout the network.

The performance criterion depends on the selection of the traffic variables to be minimized. Typical choices could be queue length, delay, and travel time. Penalty terms for state and control constraints and state weighting factors can be included to give a higher priority to selected states. Control constraints are required to ensure that all traffic directions receive the right of way. Finally, an efficient optimization procedure is required to derive the optimal signal settings to minimize the specified performance index.

### 3.3 Progression Control Systems

Most of the research for traffic control during the past decade was devoted to progression systems. The principle of this method of control is to maximize the green through bands for the two flow directions to allow drivers to pass through the intersection with minimum delay. The systems fail to account for certain conditions such as heavy traffic flow, inflow from side streets, and right and left turn traffic. It is generally known that during peak traffic periods, the progression systems are ineffective to control the traffic flow. The system depends on a time-space diagram, where the abscissa represents time and the ordinate represents signal spacing. Two parallel lines having a slope equal to a specified vehicle speed are drawn for each direction. The distance between the two lines, known as the bandwidth, is maximized such that the maximum number of vehicles can move through the intersection. The system depends on the average speed of the vehicles (vehicles arrive in a platoon rather than individually). The desired vehicle speed can be varied between intersections (Fig. 3-1).

Whenever traffic flow is undersaturated (less than capacity and

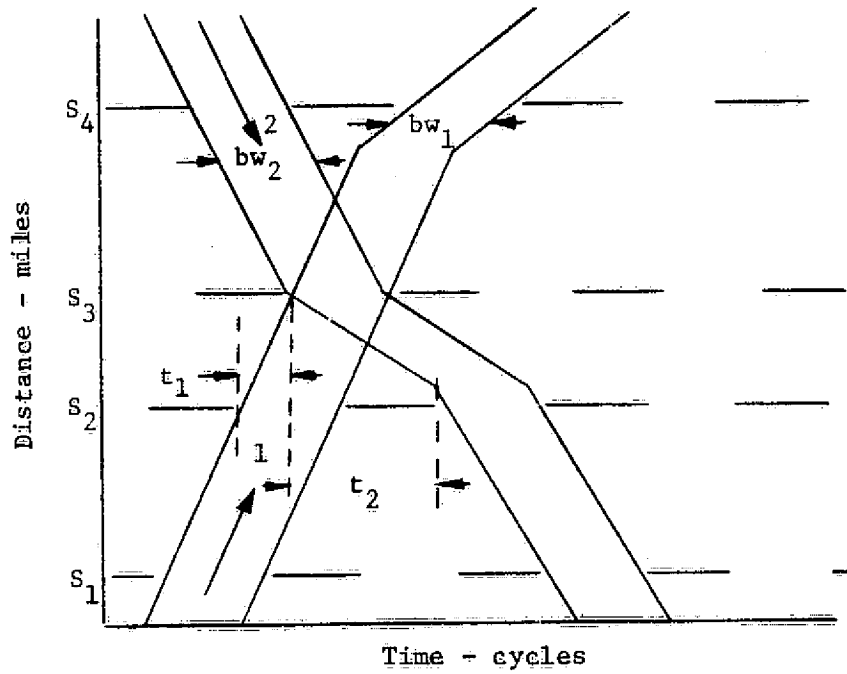


Figure 3-1. - Time - space diagram.

Notation:

$S_1, S_2, S_3, S_4$	signalized intersections
$bw_1$	bandwidth in direction 1
$bw_2$	bandwidth in direction 2
$t_1$	offset between signals $S_2$ and $S_3$
$t_2$	offset between signals $S_3$ and $S_2$
<hr/>	red band

freely moving), the progression system performs satisfactorily. During peak traffic periods, the system fails to limit the queue build-up at intersections. The reason is that for oversaturated arteries (flow above capacity), the net inflow to the link is positive and the density increases above capacity. According to Gazis (9), the solution is to synchronize the traffic signals and provide maximum green through band for congested links. This method permits a higher flow in the direction of heavy traffic while allowing less flow in the opposite direction.

Most of the effort in this area has been directed towards improving the traffic model and employing various optimization procedures to obtain improved solutions to a progression model. The various techniques are presented in the following sections.

3.3.1 Bandwidth techniques. - A computational procedure to optimize the bandwidth of a progression system was developed by Little (25) using mixed integer linear programming. The algorithm computes the offset between intersections, cycle time, and vehicle speed to maximize the bandwidth in both flow directions. The program has considerable flexibility in that it permits variations in speed (between intersections) and in cycle time. The program considers the interactions between these two variables, although assumes the vehicle speed and flow between intersections remain constant. The procedure uses an off-line optimization method.

Bleyl (2) developed a computer program for designing progressive traffic-signal-system timing plans. This approach differs from the conventional progression system in that speed and distances are converted to travel time units. The basis for this approach is that the traffic signal system is not homogeneous and consistent throughout. Geometric



and traffic conditions influence the traffic flow and should be included when optimizing a progressive movement. The algorithm determines the timing plan that will yield the maximum efficiency for the traffic signal system. The program accepts all traffic variables including signal distances, vehicle speed, cycle time, splits, and offsets. Efficiency of a progression system is defined as the ratio of the sum of the widths of the two through bands to the cycle time (9).

3.3.2 MITROP model. - Gabbay, Gartner, and Little (6) developed the MITROP traffic model using mixed integer programming formulation. The control variables are cycle time, split and offset and the performance measure is the vehicle delay. The optimization procedure assures a global minimum. The program, due to its long computation time, is not adaptable to real time applications.

3.3.3 RRL (Road Research Laboratory) combination method. - The RRL combination method, developed by Hillier (19), determines the signal offsets to minimize vehicle delay within the traffic network. The method requires that the cycle time, duration of the green through bands and a delay/difference-of-offset relation are known for both flow directions. The delay is assumed as a function of the offset between intersections. The cumulative demand function (arrival rate) and the cumulative service function (departure rate) can be plotted as a function of time (fig. 3-2). The area between the two curves defines the total delay in vehicles-seconds/second. Varying the offset time will shift the cumulative service function relative to the demand function. Using this approach, a relation between vehicle delay and difference-of-offset will be generated. These data are required for each link of the network. The RRL combination method then computes the

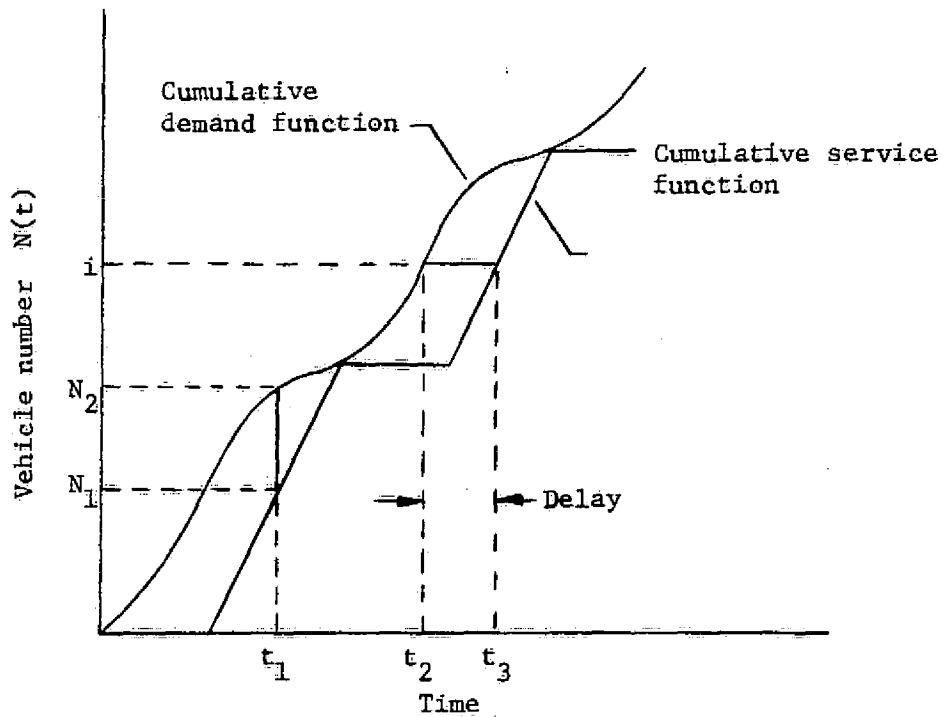


Figure 3-2. - Cumulative demand function and cumulative service function plotted to illustrate vehicle queue length and delay time for RKL combination method.

$$\text{Cumulative demand function} = \int_0^t q(t)dt$$

$$\text{Cumulative service function} = \int_0^t S(t)dt$$

$$\text{Delay time} = t_3 - t_2 \text{ (delay of } i^{\text{th}} \text{ vehicle)}$$

$$\text{Queue length} = N_2 - N_1 \text{ (number of vehicles queued at the intersection at time } t_1)$$

$q$  = arrival rate of vehicles

$S$  = service or departure rate of vehicles

offsets for all traffic signals within the network to minimize the total vehicle delay. The traffic model assumes that the vehicle platoon has constant density (no dispersion) and travels at a uniform or constant rate.

Several researchers (7,8,20,36) have improved the RRL combination method. Robertson included the effects of platoon dispersion in the TRANSYT model (section 3.3.4). Gartner (8) considers microscopic analysis of the actual flow patterns on signal controlled links. The vehicle flow into the links is derived by using loop detectors. The flow data are then processed to compute accurate offset-delay relations from which the optimal offsets can be computed. Gartner employs queuing theory to determine the total number of arrivals and departures during the red and green bands of the signal cycle. It is assumed that the arrival rate during the green band does not exceed the saturation rate. This assumption implies that if a queue disappears during the green band it cannot be formed again until the start of the next red period. Therefore, the queue is always empty at the end of the green band and delay calculations can be confined to a single interval. The delay caused by  $N$  vehicles during an interval  $dt$  is  $N dt$  (vehicle-sec) and the total delay time incurred during a complete cycle is defined by the area of the queue length curve (i.e., time from start of red band to end of green band or until queue vanishes). The average delay time per vehicle can then be defined as the total delay divided by the cumulative number of arrivals during the cycle. The offset-delay relation can be generated by varying the relative phasing between the signal settings and number of arrivals.

In a further publication, Gartner (7) considers the traffic control system as two loops: (1) a minor loop that sets the cycle time and splits at the individual intersections and (2) a major loop that considers all traffic signals as a complete system and selects the appropriate offset time throughout the network. Offset timing is computed by employing cost functions for each link of the network. These cost functions include delay and depend only on the platoon behavior at each intersection. The network is divided into smaller sections and an exhaustive search is applied to determine the optimal offset values.

3.3.4 TRANSYT model (36). - The effects of platoon dispersion were considered for the TRANSYT model using the Robertson recurrence relationship. The model is more detailed than the combination method and uses experimentally derived histograms to describe platoon behavior. The procedure has been field tested in congested areas and results indicate that a 16% reduction in travel time and a 25% increase in network capacity can be achieved. Congestion and travel time during rush hours are lower than would normally be expected for off-peak hours (36).

The technique has several advantages over the RRL combination method. The behavior of the vehicles traveling through the network is accurately modeled and a more effective optimization technique is employed. The traffic model assumes (36):

- (1) All major intersections have traffic signals or are controlled by a priority rule for traffic directions.
- (2) Traffic signals have a common cycle time.
- (3) Inflow traffic to the network is at a constant specified flow rate.

(4) The proportion of right and left turning traffic at each intersection is defined and remains constant throughout the complete cycle.

The control variables are split and offset. The performance criterion is a linear combination of delay and number of stops. The technique uses a hill-climbing optimization method. The disadvantage is that the TRANSYT program has an extremely long computation time. In its present form, the method is not applicable to real time control.

3.3.5 SIGOP model. - The SIGOP model (Signal Optimization Program) is one of the first computerized optimization programs for a traffic network (30). The procedure employs a gradient optimization algorithm to determine the ideal offset difference for each link and optimal offset for the complete network. The ideal offset difference is defined as the time difference between the initiation of the green band at the downstream signal relative to the upstream signal.

The program determines the value of the signal setting for each phase as a function of total or critical flow at each intersection, where critical flow is the maximum flow per lane at the intersection. It is assumed that ideal offset differences exist that will minimize the delay time and number of stops for the vehicles. The program computes a set of optimal offset differences to minimize the sum of squares of the difference between ideal and optimal offsets for each link. According to Munjal (30), the program cannot determine the offset differences so that all links have ideal offset differences. It is also assumed that the ideal offset difference is independent of cycle length (up to ten different cycle lengths can be evaluated) to compute optimal offsets without recomputing the ideal offset difference.

The algorithm is superior to other techniques and due to its reasonable computational requirements can be adapted to on-line traffic control.

### 3.3.6 Application of optimal control theory to traffic control. -

Akashi et al. (1) applied optimal control theory to solve the traffic control problem. The implemented system is in operation and effectively controls the traffic flow in Tokyo, Japan. The model is large enough to require the authors to divide the complete traffic system into two levels. The level of control is determined by the density of traffic flow. Traffic flow is monitored by an upper level controller using a macroscopic model; whereas the individual smaller areas are controlled by a lower level controller. The latter controller uses a microscopic model. The system is represented by a set of multi-variable nonlinear difference equations.

The control variables are the ratio of vehicles going straight, turning left and right at an intersection. The performance criterion is the uniform distribution of density throughout the complete traffic network. The objective is to minimize the congestion and eliminate it quickly whenever it occurs.

### 3.4 Conclusions

This chapter has presented the principles of progression design for traffic control systems. The major types of progression traffic control systems were briefly discussed. The differences among these systems lie in the degree of complexity and detail of the traffic model and the type of optimization procedure used to solve the problem. The methods are essentially off-line techniques due to their extensive

computational requirements. The SIGOP model could be adapted to real time traffic control.

## CHAPTER IV. TRAFFIC CONTROL MODELING

The majority of traffic control systems presently in operation are progression type systems. Standard progression systems are effective for tree networks but are further complicated by the existence of loops (11). This type of configuration is difficult to control effectively and minimize the delay time for individual drivers. In addition, in-flow from access streets and left and right turn traffic are not properly accounted for in the progression model.

### 4.1 Traffic Control Requirements

The differences among the various progression systems discussed in Chapter III is in the complexity and detail of the traffic model, assumptions, constraints, and optimization procedures. Representative techniques to describe platoon behavior and dispersion have been presented. The methods are all approximate due to the stochastic nature of the traffic problem. The accuracy of the Lighthill-Whitham theory (11,37) depends on the validity and constancy of the flow density relation; whereas the Robertson method (36,37) requires an experimental smoothing factor. The models are generally derived for a few intersections and do not include flow continuity relations.

Previous research conducted in traffic theory does not provide adequately for complete networks. The choice of model, whether microscopic or macroscopic, depends upon the objective of the traffic control system. If one considers only variables such as flow, density,



speed and travel time, then a macroscopic model is more desirable. The objective of this research effort is to develop a traffic algorithm that will compute the optimal signal settings for a traffic network. The requirements are to eliminate long vehicle queues efficiently and permit vehicles to travel through the network with minimum delay. A simplified block diagram of the elements of a traffic control system is presented in figure 4-1. This diagram illustrates one link and intersection, within a traffic network comprised of many links and intersections. If the network is large, difficulties will be encountered in attempting to solve the traffic control problem within a reasonable amount of computer time. Decomposition of the network can be realized by subdividing the system at appropriate boundaries.

At the boundaries of the network, the incoming flow must be established either with presence detectors or time-of-day flow measurements. The model must describe the vehicular flow through the links and intersections in both directions as well as right and left turning traffic. Using this modeling approach, the internal flow and number of vehicles (queue length) waiting to enter the intersections are monitored by the program throughout the controlled time interval.

An efficient optimization procedure computes the optimal signal settings to minimize a specified performance index. The choice of control variables for a traffic control system is limited to cycle time, cycle splits and offsets. The sum of the green bands and lost time equals the total cycle time of the traffic signal. Constraints must also be included to ensure minimum and maximum green bands. No matter how small the traffic flow vehicles at each intersection approach must

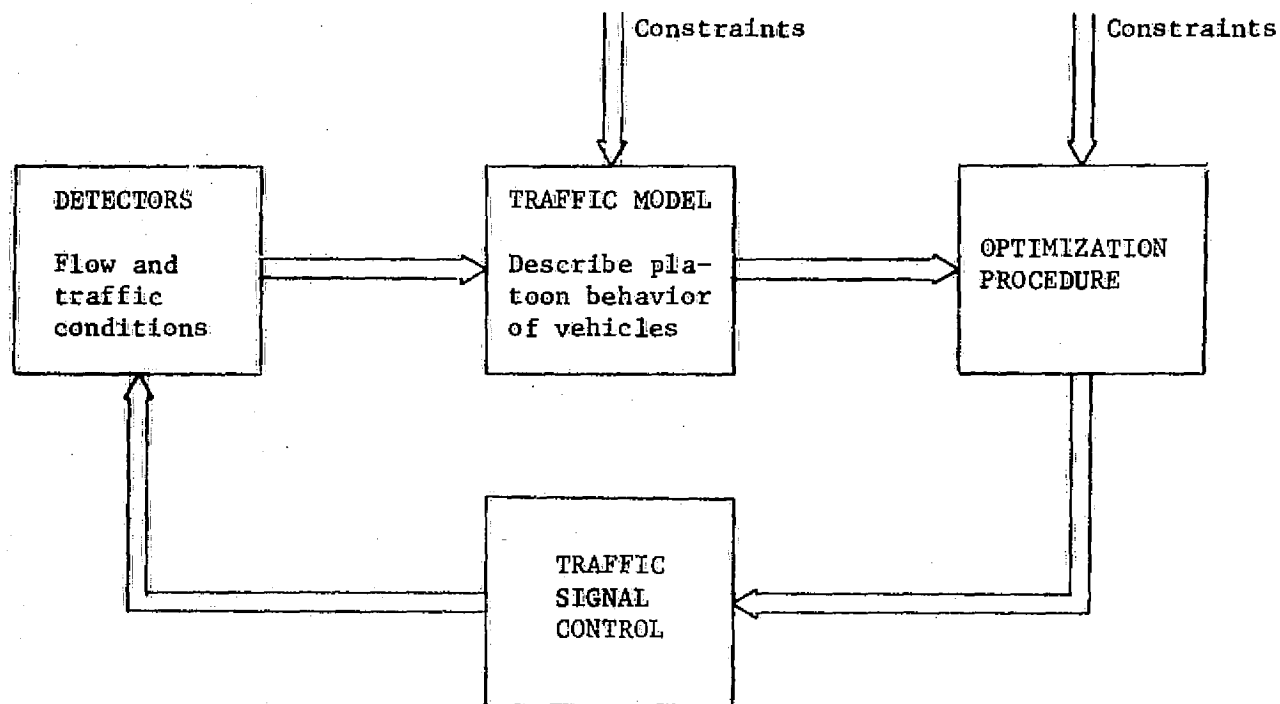


Figure 4-1. - Traffic control system.

be allowed to proceed during a cycle. If the traffic signal remains red during a major portion of the cycle, e.g., traffic is very light, drivers might be influenced to proceed through the intersection, under the impression that the traffic signal is inoperative. Other constraints are that the link storage capacity and the vehicle discharge cannot exceed the queue length.

The optimization procedure computes the optimal signal settings to reduce the queue lengths at each intersection. After the transient effects have decayed, the service rates of the intersections should be adequate to eliminate the queues at the end of the green band. If off-line optimization is considered, as for the proposed traffic control algorithm, the cycle splits must be determined from historical flow measurements. On-line procedures require a control computer to continuously monitor and adjust the traffic signals throughout the network at specified time intervals (usually 15 min) in response to varying traffic flow conditions. The pay-off of on-line optimization and control must be thoroughly examined because the solution time is extremely time-consuming. The actual settings of the signals must be delayed, although this effect may not be significant.

#### 4.2 General Traffic Models

The macroscopic model to describe the behavior of traffic flow has been used by several authors. Isaksen (22,33) has modeled freeway traffic behavior using conservation of vehicles equations. Employing suboptimal control, Isaksen developed on-ramp methods to regulate freeway traffic and restore the freeway to normal conditions after severe incidents and congestion. Isaksen uses an aggregate model that was

developed by Payne (22). These models are in terms of flow rate, density, and space mean speed. However, since freeway conditions are not always uniform, the author modifies the velocity relation to include a driver anticipation and reaction lag term.

Singh and Tamura (38) use discretized conservation equations to describe oversaturated (high flow rate) traffic behavior along urban streets with signalized intersections. The problem is formulated as a linear quadratic problem with inequality constraints on the states and pure time delays for the controls. The delays must be included to account for the travel time of platoons between intersections. The authors (38) indicate that a large-scale optimization problem cannot be solved without multi-level procedures. Singh applies Tamura's goal coordination algorithm to arrive at a solution to a two to three intersection one-way traffic network. Since the links are oversaturated and the queues cannot be eliminated, the authors compute optimal signal settings during the transient periods. This condition implies that the queue length is always greater than the outflow from the intersection. Offsets between intersections are assumed as constant values.

Kaltenbach and Koivo (23) use a similar approach to model the vehicle behavior, except that these authors convert to a continuous representation. A multi-level approach is considered, whereby the first level minimizes the total delay incurred by the vehicles over a selected control interval.

This procedure determines the optimal signal settings. The second level should be concerned with the offset between intersections. However, the authors (23) assume that these offsets are constant values. Two models are compared; a complex and realistic model and a simplified

model. Both models assume that the arrival rates at network boundaries are specified time functions whereas the time delay (offset) corresponds to the travel time of a vehicle from the instant it departs the intersection to the time it arrives at the next intersection. Therefore, the authors (23) assume a constant vehicle speed and distance to compute the desired offset. Since the model cannot consider driver reaction time, a quadratic term is included in the performance criterion. This term accounts for the delay encountered between movement of the front and rear vehicles of a platoon. This cost functional also penalizes long queues more heavily than short queues. The simplified model does not account for saturation conditions in the adjoining links. A realistic traffic model must monitor the number of vehicles in a link before additional vehicles can be discharged. This constraint cannot be neglected, especially for short links that can only store a limited number of vehicles.

#### 4.3 Proposed Traffic Model

The traffic theory presented in the two references by Singh (38) and Kaltenbach (23) serve as a basis for the proposed traffic model. Extensions of these principles are applied to form a mathematical model for a large-scale traffic network with flow in both directions (two-way) and right and left turning traffic. The model is formulated using conservation of vehicles and flow continuity equations to mathematically describe the behavior of the vehicle queues and flow interaction between the intersections of a traffic network. The size of the network, i.e., the number of states (queues) and controls (traffic signals) is limited by economics and computer availability. If the network size can be reduced, or if small variations occur in the flow into

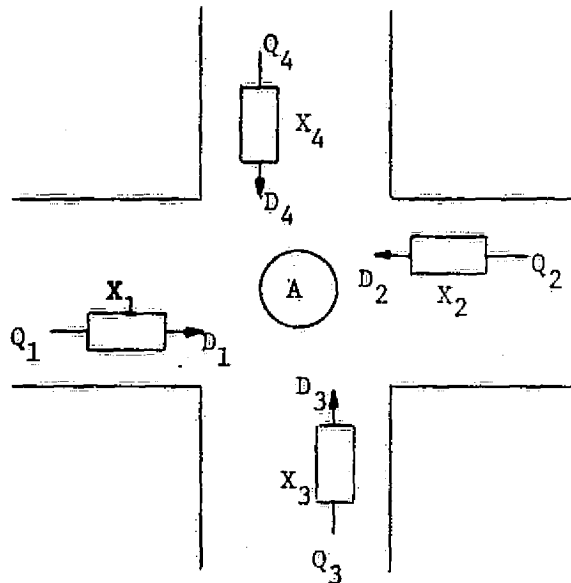
the boundaries, the algorithm can be reoptimized within a reasonable amount of computer time. Decomposition can also be applied by dividing the complete network into smaller subnetworks. To ensure acceptance of the traffic control system, the computation time and costs must be reasonable and the control system must be implemented in an efficient and expedient manner.

Vehicles usually travel in bunches or platoons. When traffic flow is not heavy, leading vehicles in each lane accelerate according to an exponential law while the followers obey one of the car-following laws and can overtake leading vehicles provided that there exists sufficient clearance between vehicles (37). If the traffic is dense or the network is oversaturated, then a macroscopic model adequately describes the behavior of the platoons. The objective of the traffic algorithm dictates the complexity and detail of the model, but the ultimate goal is to accurately describe the behavior of the queues and dissipate the queues effectively. The optimization determines the signal settings to minimize queue lengths and congestion at the intersections which in effect should also reduce the waiting and travel time for each driver. A priority system is established, whereby longer vehicle queues receive a larger portion of the green through band. The model is formulated by a set of linear discrete difference equations with state and control constraints. The system is reduced to an open loop optimal control problem using a quadratic performance criterion.

The complete traffic network is subdivided into many intersections and links. Vehicle queues are established and may be classified as main stream (straight) and left and right turning queues. Whenever a vehicle platoon passes through the intersection, its subsequent move-

ment is established by the flow continuity equations. The traffic model assumes that all vehicles leaving an intersection must proceed to another intersection. The model does not consider vehicles that park or leave the network except at specified boundary locations. Such provisions can easily be included in the model.

4.3.1 Description of modeling approach. - The modeling approach can be demonstrated for a single intersection with two-way traffic. Consider the following example.



Define

$X_i$  length of vehicle queue in direction  $i$  (number of vehicles per cycle)

$Q_i$  arrival rate of vehicles in direction  $i$  (number of vehicles per cycle)

$D_i$  departure rate of vehicles in direction  $i$  (number of vehicles per cycle)

$U$  fraction of green band in direction  $i$  to total green band  
 $S_i$  service rate of vehicles in direction  $i$  (number of vehicles per cycle). Service rate is defined as the maximum number of vehicles that can pass through the intersection during the entire cycle time, i.e., the green band is equal to the cycle time.

$\alpha_i$  fraction of total cycle time allotted to green bands.

$$\alpha_i = \text{cycle time} - \text{lost time}$$

$k$  sampling time (cycles)

$i$  direction of traffic

For the above example, the model equations become:

$$X_1(k+1) = X_1(k) + Q_1(k) - D_1(k)$$

$$X_2(k+1) = X_2(k) + Q_2(k) - D_2(k)$$

$$X_3(k+1) = X_3(k) + Q_3(k) - D_3(k)$$

$$X_4(k+1) = X_4(k) + Q_4(k) - D_4(k)$$

(4-1)

where

$$D_1(k) = S_1 U(k)$$

$$D_2(k) = S_2 U(k)$$

$$D_3(k) = S_3 (\alpha - U(k))$$

$$D_4(k) = S_4 (\alpha - U(k))$$

(4-2)

The cycle length of a traffic signal is the total time allowed for one complete sequence of signal indications. This time includes the green band for both directions of traffic flow, left and right turn signals and amber and clearance delays. Therefore,



$$C = G_1 + G_2 + G_{\text{left}} + \text{lost time}$$

(4-3)

$$U = G_1 / (C - \text{lost time}) \quad \text{or} \quad G_2 / (C - \text{lost time})$$

where

C cycle time

$G_1$  green band for one flow (e.g., N-S) direction

$G_2$  green band for other flow (e.g., E-W) direction

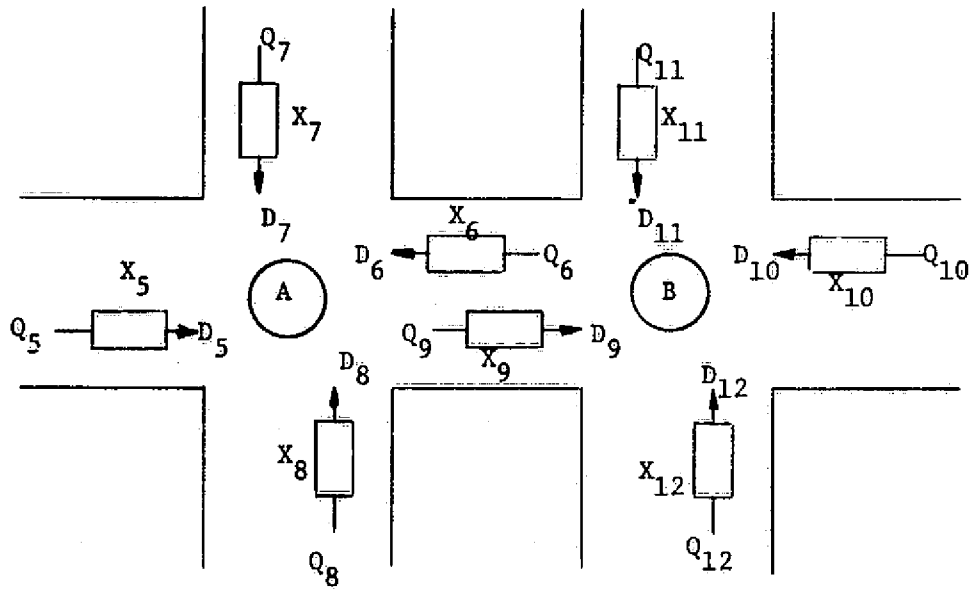
Several constraints must be considered for the traffic model. For the single intersection, the inequality constraints are as follows:

1. Number of vehicles waiting in the link must be equal to or greater than zero -  $X_1 \geq 0$ .

2. Number of vehicles waiting in the link must be equal to or less than the maximum number  $X_m$  that can be stored in the link -  $W(k) \leq X_m$ ; where  $W(k) = X(k) + Q(k)$  and  $X_m$  is the maximum number of vehicles that can be stored in the link.

3. Minimum and maximum green bands must be imposed. This condition is to ensure that directions with minimum traffic flow are allotted a green band to allow drivers to proceed at some time during the signal cycle.  $0 < U_{\min} \leq U \leq U_{\max}$

Using the same techniques described for the single intersection model, a two intersection model can be described as shown. Assume two controls -  $U_A$  is the green band for flows 5 and 6, and  $U_B$  is the green band for flows 9 and 10.



Two Intersection Network

The model equations become:

$$X_5(k+1) = X_5(k) + Q_5(k) - D_5(k)$$

$$X_6(k+1) = X_6(k) + Q_6(k) - D_6(k)$$

$$X_7(k+1) = X_7(k) + Q_7(k) - D_7(k)$$

$$X_8(k+1) = X_8(k) + Q_8(k) - D_8(k)$$

$$X_9(k+1) = X_9(k) + Q_9(k) - D_9(k)$$

$$X_{10}(k+1) = X_{10}(k) + Q_{10}(k) - D_{10}(k)$$

$$X_{11}(k+1) = X_{11}(k) + Q_{11}(k) - D_{11}(k)$$

$$X_{12}(k+1) = X_{12}(k) + Q_{12}(k) - D_{12}(k)$$

(4-4)

where

$$D_5(k) = S_5 U_A(k)$$

$$D_6(k) = S_6 U_A(k)$$

$$D_7(k) = S_7 (\alpha_A - U_A(k))$$

$$D_8(k) = S_8 (\alpha_A - U_A(k))$$

$$D_9(k) = S_9 U_B(k)$$

$$D_{10}(k) = S_{10} U_B(k)$$

$$D_{11}(k) = S_{11} (\alpha_B - U_B(k))$$

$$D_{12}(k) = S_{12} (\alpha_B - U_B(k))$$

(4-5).

The incoming flows ( $Q_5, Q_7, Q_8, Q_{10}, Q_{11}, Q_{12}$ ) to the boundaries of the network must be determined from historical data. Flows  $Q_6$  and  $Q_9$  are internally generated and are established from the discharge conditions of the intersections. For the example, assume that all flows move in the direction as shown in the diagram, then the two flows can be represented as follows:

$$Q_6(k) = S_{10} U_B(k - \gamma_{BA}) = D_{10}(k - \gamma_{BA})$$

(4-6)

$$Q_9(k) = S_5 U_A(k - \gamma_{AB}) = D_5(k - \gamma_{AB})$$

A pure time delay term  $\gamma$  is now introduced into the flow equations. The number of vehicles discharged from intersection A that proceed to intersection B become the delayed input to intersection B. Similarly, the vehicles discharged from Intersection B become the input flow to intersection A. The terms  $\gamma_{BA}$  and  $\gamma_{AB}$  are integers that represent the time delay (travel time in cycles or fractional cycles) for the platoon to move between the two intersections. The magnitude of the delay term depends upon the distance between the intersections and the

average speed of the vehicles. The  $X_6(k+1)$  and  $X_9(k+1)$  equations can be rewritten as:

$$X_6(k+1) = X_6(k) + D_{10}(k - \gamma_{BA}) - D_6(k) \quad (4-7)$$

$$X_9(k+1) = X_9(k) + D_5(k - \gamma_{AB}) - D_9(k)$$

where the  $D_5$  and  $D_{10}$  terms represent the delayed inputs to the intersection. Link constraints are also required for the model.

The network can be represented by linear vector matrix difference equations with time delays in the controls (38) and inequality constraints.

$$\bar{X}(k+1) = A\bar{X}(k) + B_1\bar{U}(k) + B_2U(k - \gamma) + G \quad (4-8)$$

where

$$\bar{X}^T = [X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}]$$

$$\bar{U}^T = [U_A, U_B]$$

$$\bar{U}(k - \gamma)^T = [U_A(k - \gamma), U_B(k - \gamma)] \quad \gamma_{AB} = \gamma_{BA} = \gamma$$

A is the identity matrix

$$B_1^T = \begin{bmatrix} -S_5 & -S_6 & S_7 & S_8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -S_9 & -S_{10} & S_{11} & S_{12} \end{bmatrix}$$

$$B_2^T = \begin{bmatrix} 0 & 0 & 0 & 0 & S_5 & 0 & 0 & 0 \\ 0 & S_{10} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$G^T = [Q_5, 0, (Q_7 - S_7\alpha_A), (Q_8 - S_8\alpha_A), 0, Q_{10}, \\ (Q_{11} - S_{11}\alpha_B), (Q_{12} - S_{12}\alpha_B)]$$

where the  $k$  are omitted for simplicity. For traffic networks with several intersections, additional constraints are included to ensure

that the discharged vehicles can be accommodated within the adjoining links. These constraints are as follows:

(a) For unsaturated links (Link storage capacity is not exceeded)

1. If the queue lengths are greater than the number of vehicles that can be discharged -  $W(k) \geq D(k)$ , then  $D(k) = SU(k)$ .

2. If the queue lengths are less than the number of vehicles that can be discharged -  $W(k) \leq D(k)$ , then  $D(k) = W(k)$ .

(b) For saturated links

1. If the queue lengths are greater than the number of vehicles that can be discharged -  $W(k) \geq D(k)$ , then

$D(k) = \min[D(k), X_{j+1}^{\max}]$  where  $W(k) = X(k) + Q(k)$  and  $j + 1$  is the adjoining intersection.

2. If the queue lengths are less than the number of vehicles that can be discharged -  $W(k) \leq D(k)$ , then

$D(k) = \min[W(k), X_{j+1}^{\max}]$ .

Therefore, for each sampling interval the downstream link must be monitored and the number of vehicles that can be discharged by all queues depends on the status of the link. The sampling can only occur during the previous sampling interval, so that vehicles could be discharged before a new platoon arrives at the intersection. This constraint is extremely important for short links where few vehicles can be stored.

The objective of the traffic control algorithm is to minimize the queuing time spent at each intersection. An appropriate performance criterion for this application is as follows:

$$P = \frac{1}{n} \left\{ \bar{W}^T(p) R_1 \bar{W}(p) + [\bar{U}(p) - \bar{U}_d]^T R_2 [\bar{U}(p) - \bar{U}_d] \right\} \quad (4-9)$$

where

$$\bar{W}^T = [W_1, W_2, W_3, \dots, W_n]$$

$$\bar{U}^T = [U_1, U_2, U_3, \dots, U_m]$$

$\bar{U}_d$  desired control setting

$R_1$  weighting factor for queues (states)

$R_2$  weighting factor for controls

$n$  number of states

$m$  number of controls

$p$  time of optimization. The value of  $p$  is selected after the transient effects have decayed.

A quadratic performance index was selected as it penalizes the longer queues more heavily than the smaller queues. The performance factor was evaluated after transient effects have decayed, since "steady state" conditions are of primary interest. This condition is more realistic and more efficient to implement than optimizing at the end of each signal cycle. The quadratic term also ensures that the rear vehicles cannot move before the front vehicles (23). By varying the weighting factor  $R_1$  selected queues can be penalized more heavily thus forcing these queues to lower levels. This condition is desirable to clear specified queues to prevent congestion or clear incidents. The weighting factor  $R_2$  is normally zero unless specified signal settings must be maintained at preselected levels. The weighting factor  $R_2$  is also applicable to satisfy the minimum and maximum constraints for control settings.

Using the above stated principles, a model of the traffic network can be formulated. Vehicle queues for all possible traffic movements, either real or fictitious can be established. Fictitious queues are

defined as queues that cannot be explicitly defined. For example right and left turn queues may be part of the main stream traffic but separate at the intersection. All phasing combinations, such as main stream, left and right turning traffic, phase lead and lag, were formulated for the queues at each intersection. Vehicle flows from network boundaries are obtained from historical data, whereas all internal flows, other than initial conditions, are generated from the discharge conditions of the intersections. The initial flow conditions are required to start the traffic algorithm since actual flows cannot be defined accurately by the flow continuity equations at the start of the optimization process. Initial queue lengths must be specified for each queue. However, the number of vehicles waiting at the intersection at the start of the process only influences the number of signal cycles required to eliminate the queues but does not contribute to the growth of the queues. This factor is only influenced by the arrival rates of the vehicles and the service rates of the intersection.

The linear vector difference equation for a complete network is of the general form:

$$X(k+1) = AX(k) + B_1U(k) + B_2U(k - \gamma_2) + \dots + B_mU(k - \gamma_m) + G_1$$

where the  $A, B_1, B_2, \dots, B_m, G_1$  terms are derived from the mathematical formulation of the network.

The next phase of the traffic analysis is the selection of an optimization procedure to solve the control problem. The optimization of large-scale systems is a difficult and time-consuming process. The following chapter will discuss the procedure selected for the traffic problem.

## CHAPTER V. OPTIMIZATION TECHNIQUES

After a representative traffic model has been developed, the next step is to optimize the control variables to minimize the lengths of the vehicle queues throughout the network. The selection of an efficient optimization procedure is a difficult task due to the high dimensionality of the problem and the existence of state and control inequality constraints. The procedure selected should optimize the traffic network within reasonable computer time constraints to ensure cost effectiveness of the traffic algorithm.

One approach to optimizing large-scale systems is to decompose the network into a set of subsystems each with its own solution and constraints. This method is referred to as multi-level optimization. The principle of one such procedure is that an upper level system controls a lower level system. Estimates of the lower level control variables (interaction variables) are transmitted to an upper level which calculates improved estimates of its control variables. These estimates are sent to the lower level which in turn calculates improved estimates of its control variables. This procedure is repeated until optimum values are derived. An iterative method is used for the optimization problem whereby the task is divided between the two levels (39).

Some large-scale systems cannot be easily decomposed into smaller systems and optimized independently under individual constraints within the smaller systems. The traffic model under consideration is not easily partitioned since the internal flows are all interrelated. A



single stage optimization process was developed by assuming a constant platoon travel time between intersections. Essentially, measured travel times were used for the internal flows within the network. The model is valid for heavy traffic flow so that the optimization of the "offset" was not a consideration.

Singh and Tamura (38) demonstrated the applicability of the goal-coordination algorithm to optimize two or three intersections (tree network) with one-way traffic flow. The authors assume a constant offset between intersections. Their procedure was used to optimize the traffic network at the end of each signal cycle.

The optimization procedure selected for the analysis of the traffic models in this dissertation is the Zangwill-Powell method (41). This technique determines the unconstrained minimum of a function of several variables without calculating derivatives. The method is more efficient than other optimization procedures. However, its limitation is that it does not recognize constraints on the variables. The constraints must be included either in the model or the performance criterion. The Zangwill-Powell method is a conjugate direction search with the property of quadratic convergence.

The traffic signal settings were optimized using an IMSL (21) subroutine ZXPOWL. The program only requires initial approximations for the control variables, desired accuracy and maximum number of iterations. The procedure then searches along linearly independent coordinate directions by successively perturbing each control variable. Powell modified his original method such that conjugate directions are selected by defining a new direction after each iteration. The manner in which the directions  $\xi_1, \xi_2, \dots, \xi_n$  are defined ensures that if

a quadratic cost index is being minimized, convergence to a minimum will be obtained in a finite number of iterations. After the directions are mutually conjugate ( $\xi_1^T A \xi_2 = 0$ ), then the absolute minimum value is obtained (34). The method ensures satisfactory convergence for quadratic functions with poor initial approximations for the control variables.

Zangwill (41) states that Powell's procedure may not converge to the minimum value of a quadratic performance index in a finite number of iterations but may never converge in any number of iterations in certain instances. Powell (34) noted this condition, especially for functions of more than five variables and has modified the procedure. His original method could fail because the directions  $q_1, q_2, \dots, q_m, m \leq n$  may not span the  $m$ -dimensional space. The procedure may thus generate directions that are linearly dependent. Thus theorem I (34) must include the additional hypothesis that the directions  $q_1, q_2, \dots, q_m$  span the  $m$ -dimensional space.

A departure from Powell's procedure is required to test the linear dependence of the directions. During the first iteration step, a multiplier  $\beta$  must be observed. If  $\beta \neq 0$ , the procedure continues normally. If  $\beta = 0$ , then the first iteration step is repeated. If this step must be repeated  $n$  times (where  $n$  is the number of normalized directions), the process is stopped. This condition indicates that the point  $p$  is optimal and the normal process can be continued. Zangwill reasons that if the step is repeated  $n$  times in succession, then all coordinate directions have been searched and the point is valid and optimal. This situation can only occur if the gradient of the function  $f$  is zero. Because the procedure assumes that the function  $f$  is

strictly convex and continuously differentiable, the point must be optimal. Brent (3) points out that it is unlikely that  $\beta$  will vanish exactly. However, Powell has suggested that the coordinate directions may become nearly dependent.

## CHAPTER VI. RESULTS OF PROPOSED TRAFFIC CONTROL ALGORITHM

The theory for the proposed traffic control algorithm presented in the preceding two chapters was applied to an actual traffic network. The chosen system consists of thirty-three controllable intersections. The complete network was subdivided into three subsystems of eleven intersections. The phasing and signal settings of the selected intersections can be monitored and controlled from a central control panel. The justification to decompose the network into three subsystems is that systems with a smaller number of states and control variables can be more easily optimized. The network could logically be subdivided into two lattices and one tree network. For this dissertation, a lattice and a tree network were modeled and optimized to demonstrate the effectiveness of the traffic control algorithm. The results for the selected networks are presented in chapter VII.

The models were formulated, as described in chapter IV, by using the conservation of vehicles and flow continuity equations. The discharged vehicles from the various intersections throughout the network were assumed to travel either to consecutive intersections or depart from the network. Parking and entrance from and into side streets were not included in this model, although these refinements could easily be included. The models are formulated in a generalized manner with traffic flow permitted in all allowable directions. The models were established to conform as much as possible to the existing traffic patterns, to permit all drivers to proceed safely through the inter-

sections. Phase lead, lag and left turn controls were included if presently utilized or if such inclusion was necessary for improved traffic control. Right turns are only permissible with a green band for main stream traffic or under special circumstances such as "T" intersections where traffic can only proceed in a limited number of directions. Unless specially marked traffic lanes are provided, there is no assurance that all waiting vehicles will turn. Link constraints such as storage of vehicles must be considered for short links with limited storage capability.

The models were generated from traffic drawings and data supplied by the Toledo Division of Traffic Engineering. These data were converted to per cycle quantities by representing arrival, departure, and service rates as number of vehicles per cycle. Traffic data were furnished for three time intervals, each with a period of 2 to 3 hours. The average inflow at the boundaries of the network was computed over the specified time intervals. Service rates were assumed as 1600 vehicles/lane/hour for main stream traffic and 1000 vehicles/hour for turning traffic. Traffic data indicate that the capacity of unimpeded roadways is normally 1800 vehicles/lane/hour with a reduction of 1.6:1 for turning traffic. These service rates can be modified to include abnormal traffic conditions such as traffic incidents, road blockage, or weather conditions. The travel time for the platoons was determined from actual travel data recorded by the Traffic Engineering Division. These fractional cycles for delay time required a time scaling of the problem.

A 10:1 time scale implies that the queue lengths are computed at 0.1 cycle intervals. The vehicles can enter the various links during

any portion of the cycle and are discharged during the green portion of the signal cycle. It can be assumed that the vehicles will arrive in platoon form since a major portion of the arriving vehicles will come from the main stream traffic of the preceding intersection. Although the queue lengths will vary during the signal cycle, the final queue length will be specified at the end of each cycle. This situation is illustrated in figures 6-3 to 6-6 showing the dissipation of the queues.

The optimization of the algorithm was limited to the steady state condition after the transient effects of most queues have decayed. The end of the ninth cycle was established as the time at which all queues have reached this steady state condition. The reason for this choice is that optimization at the end of each cycle would be impractical, costly, and difficult to implement without computerized equipment. The quadratic performance index (4-9) is the average of the summation of the squares of all the vehicle queues in the link; i.e., the queue length at the start of the red band and the arriving vehicles during the cycle.

The cost index was modified to the square root so that a large sensitivity change occurs whenever the magnitude becomes less than unity. For values greater than unity, the slope about the minimum value makes it more difficult to observe an absolute minimum.

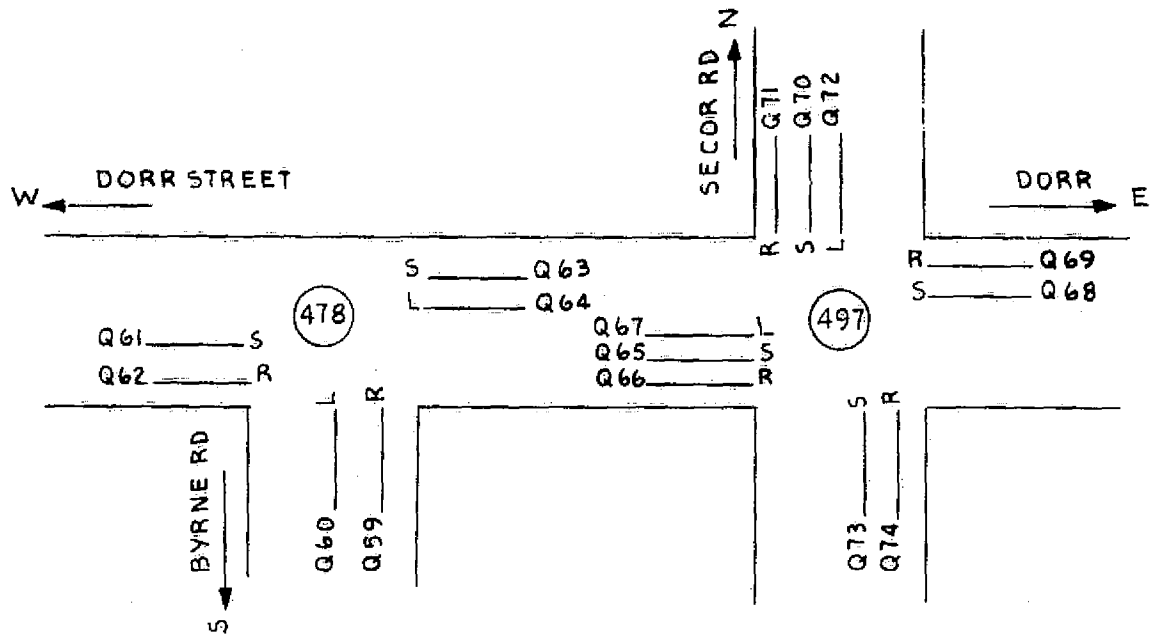
The results of the optimization indicate that for specified flow conditions, the signal settings are adequate to eliminate the vehicle queues within a reasonable number of signal cycles. The assigned signal setting for left turn traffic was maintained at a constant value

during a given time interval. For special situations, such as heavy traffic flow and possible congestion, the required green band was also derived optimally. A feature of the performance index is that selected queues can be weighted more heavily, as illustrated later, to clear and eliminate congestion of these critical queues more effectively. A provision for the difference between computed and desired signal settings is included to force the control variables to desired values. These terms also ensure that the control variables are maintained within the allowable limits.

#### 6.1 Results of Two Intersection Model

Two intersections were investigated independently to determine the optimal signal settings to eliminate traffic congestion for internal queues. The intersections are Byrne-Dorr (#478) and Secor-Dorr (#497). The model was formulated by using phase lead and a controlled left turn arrow at both intersections. Right turns from Byrne-Dorr and Secor-Dorr were allowed only with the main stream traffic. A diagram of the two intersections is presented in figure 6-1.

Initially, the optimal signal settings were computed for equal state weighting with all control weighting factors set to zero. The four controls, identified in figure 6-1, are for E-W, N-S directions and left turn traffic. The second phase of the analysis uses increased state weighting factors to ensure that the internal queues (X63 - X67) are quickly cleared and remain uncongested during the specified time intervals. This condition can be achieved only by allowing the external queues to increase substantially. In essence, traffic inflow to the network is restricted, a fact which indicates a higher flow than can be accommodated by the intersections. The analysis assumes that



## NOTE:

S - MAINSTREAM  
 R - RIGHT TURN  
 L - LEFT TURN

## INTERSECTION NO. 478

U7 - BYRNE TRAFFIC  
 U7A - DORR-BYRNE LT

## INTERSECTION NO. 497

U8 - DORR TRAFFIC  
 U8A - DORR-SECOR LT  
 DEL8 - SECOR-DORR LT

Figure 6-1. - Two intersection network. Byrne-Dorr-Secor.



the number of vehicles that must be stored within the link does not exceed the maximum storage limit.

The optimal signal settings for a weighted performance index are presented in table 6-1. As can be noted from table 6-1, the minimum control limit was not observed because the primary objective was to eliminate congestion. Figures 6-2 to 6-2(a) present the required signal phasing diagram. The offset between the signals (start of green) should be 0.3 cycles to compensate for the travel time of the platoons. The offset is normally applied to the direction of higher flow.

The dissipation of the vehicle queues for the 7 to 9 a.m. period are presented in figures 6-3 to 6-3(c). For equal state weighting (solid lines), the right turn Secor-Dorr (X71) is unstable and grows rapidly, whereas all other queues reduce eventually or remain at a constant level. For both initial queue lengths, the critical left turn queue (X67) will not reduce to acceptable levels. For unequal state weighting (dotted lines), the left turn queues (X64, X67) are eliminated within several cycles. However, large queue buildup will be experienced for the external queues (X59, X71). Allowing a right turn into Dorr will eliminate this condition without causing severe congestion for the internal queues. For the complete traffic network, right turns were permitted at these intersections. As a result no queue build-up was encountered. The long vehicle queues might encourage drivers to seek alternate routes to their destinations. Special monitoring devices could inform drivers that congestion lies ahead.

The procedure was repeated for the 11 to 1 p.m. interval. The results are illustrated in figures 6-4 to 6-4(c). The unequal state

TABLE 6-1. - OPTIMAL CONTROL SETTINGS

[Intersections 478-497 unconstrained links]

	7-9 a.m.	11-1 p.m.	3-6 p.m.
No. 478			
Byrne N-B	0.243	0.208	0.188
Dorr W-B	.657	.692	.712
Dorr E-B	.307	.130	.198
Left turn - Dorr to Byrne	.350	.562	.514
No. 497			
Dorr E-B	.609	.559	.616
Dorr W-B	.068	.116	.164
Left turn - Dorr to Secor	.541	.443	.452
Secor S-B	.291	.341	.284
Secor N-B	.091	.141	.084
Left turn - Secor to Dorr	.200	.200	.200
Performance cost	48.92	205.36	503.8

Cycle time = 90 sec

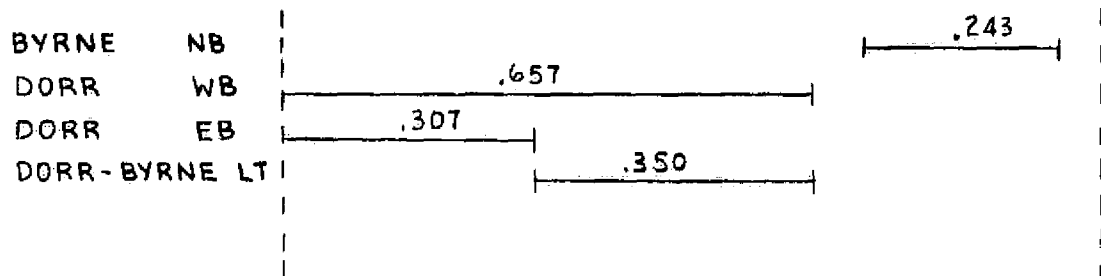
Lost time = 0.10 cycles

Offset - East-west traffic on Dorr - 0.3 cycle

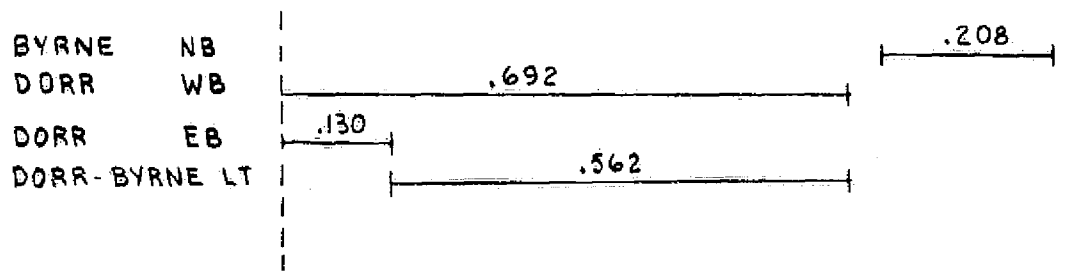
Performance index - P

$$\begin{aligned}
 P = \frac{1}{16} & \left\{ W_{59}(91)^2 + W_{60}(91)^2 + W_{61}(91)^2 + W_{62}(91)^2 \right. \\
 & + R_{63}(W_{63}(91))^2 + R_{64}(W_{63}(91))^2 + R_{65}(W_{65}(91))^2 \\
 & + R_{66}(W_{66}(91))^2 + R_{67}(W_{67}(91))^2 + W_{68}(91)^2 + W_{69}(91)^2 \\
 & + W_{70}(91)^2 + W_{71}(91)^2 + W_{72}(91)^2 + W_{73}(91)^2 + W_{74}(91)^2 \\
 & + R_7(U_7(91) - U_{d7})^2 + R_{7A}(U_{7A}(91) - U_{d7A})^2 \\
 & \left. + R_8(U_8(91) - U_{d8})^2 + R_{8A}(U_{8A}(91) - U_{d8A})^2 \right\}
 \end{aligned}$$

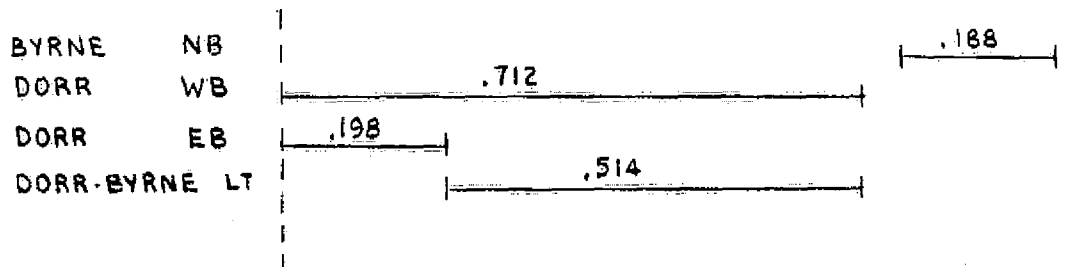
CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

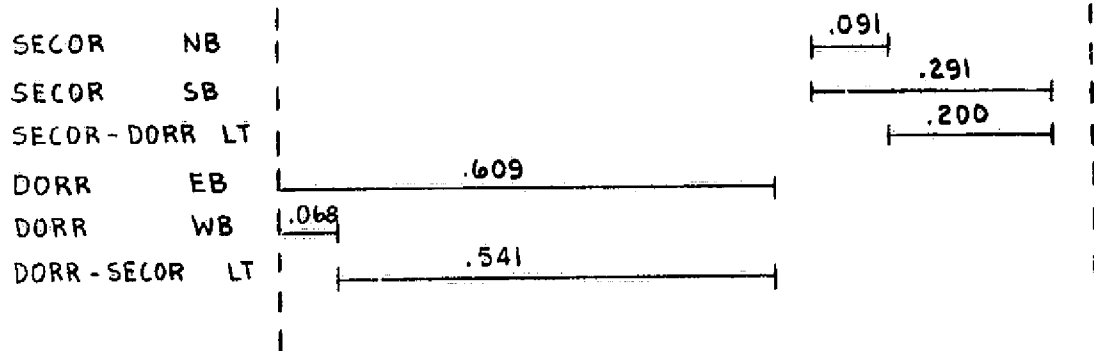


NOTE:

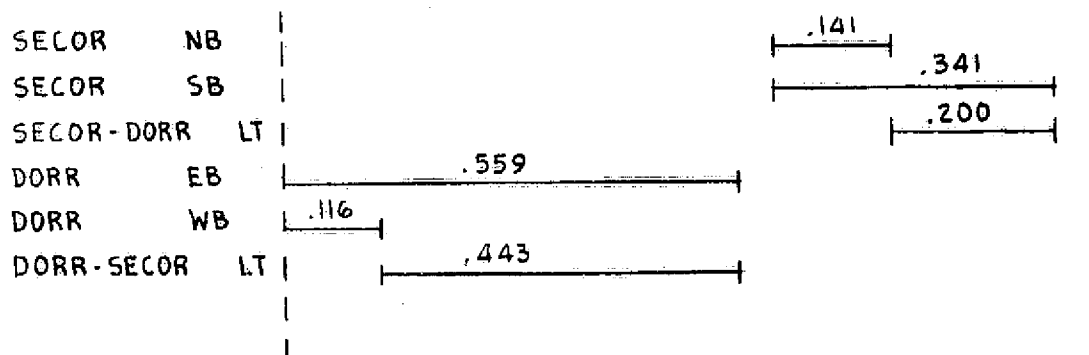
NB - NORTH BOUND  
SB - SOUTH BOUND  
WB - WEST BOUND  
EB - EAST BOUND  
LT - LEFT TURN  
RT - RIGHT TURN

Figure 6-2. - Traffic signal timing plan, intersection 478, Byrne-Dorr, unconstrained links.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

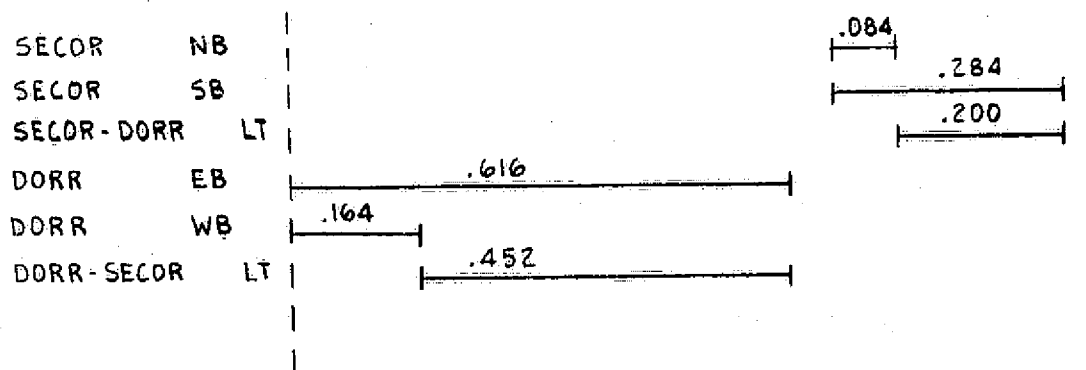


Figure 6-2(a). - Traffic signal timing plan, intersection 497, Dorr-Secor, unconstrained links.

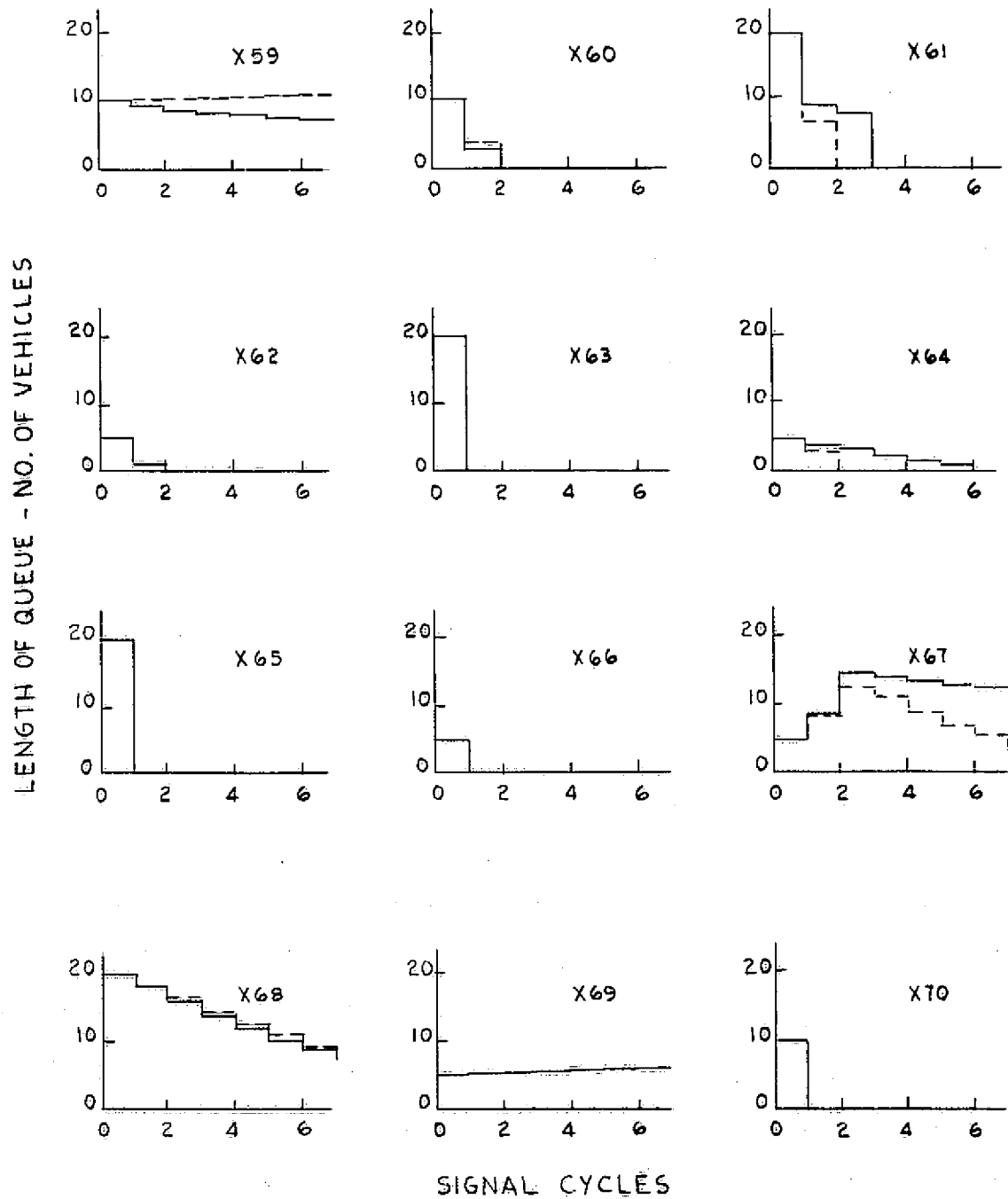
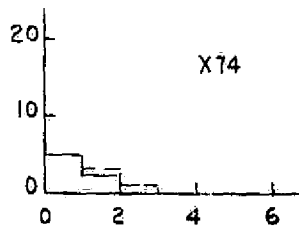
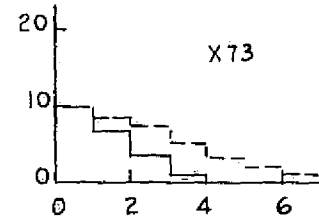
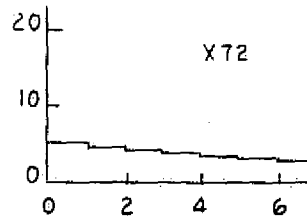
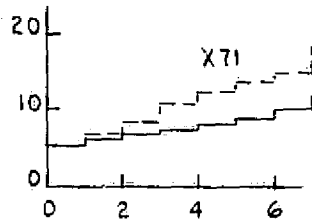


Figure 6-3. - Dissipation of vehicle queues - 7-9 a.m., Secor-Dorr-Byrne - unconstrained links.

LENGTH OF QUEUE - NO. OF VEHICLES



NOTE:

—  $R_{63} - R_{67} = 1.0$   
 ---  $R_{63}, R_{65}, R_{66} = 1.0$   
 $R_{64} = 5.0, R_{67} = 50.0$

SIGNAL CYCLES

Figure 6-3(a). - Continued.

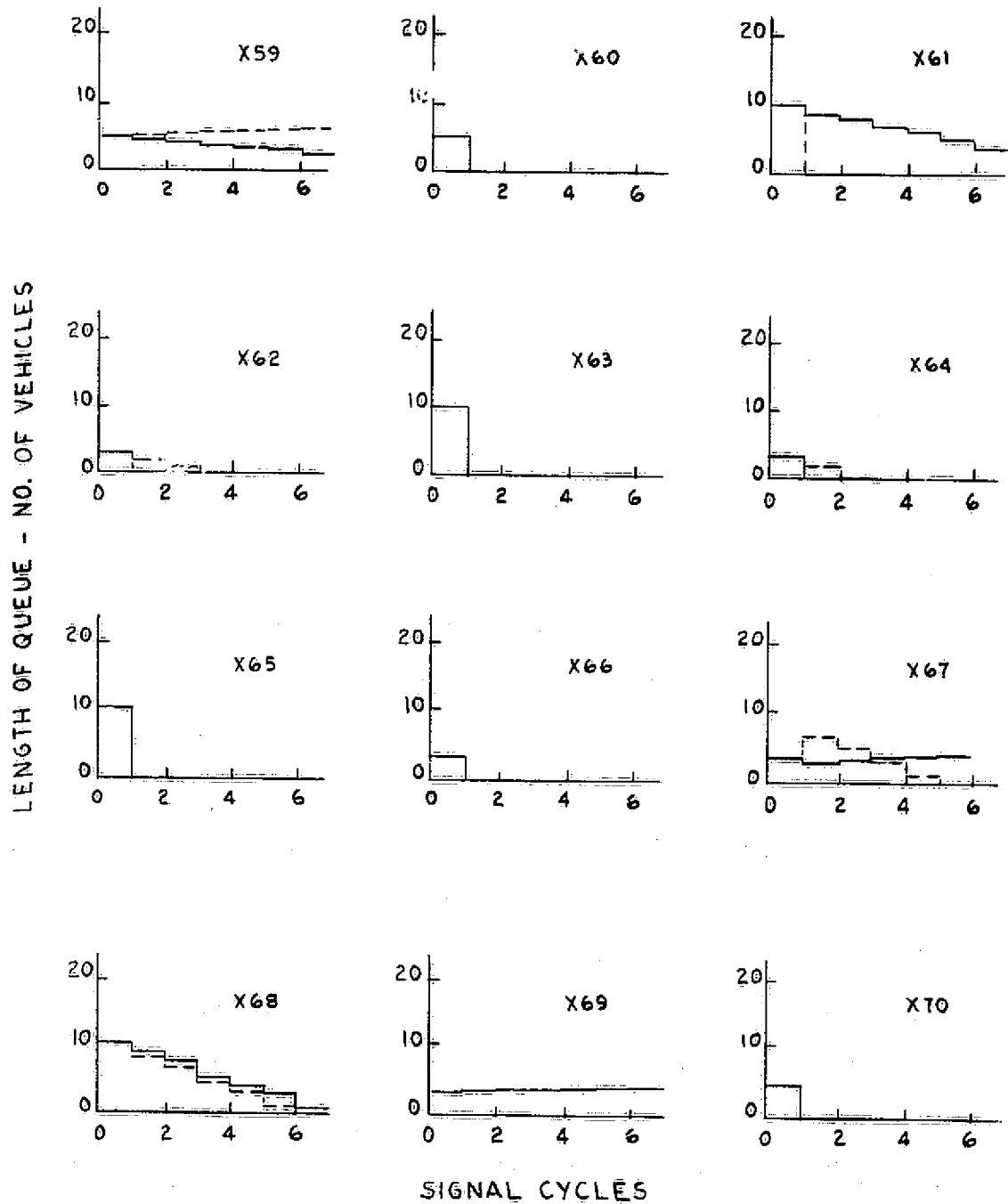
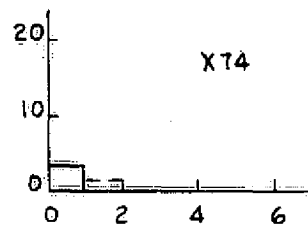
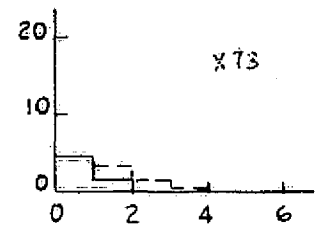
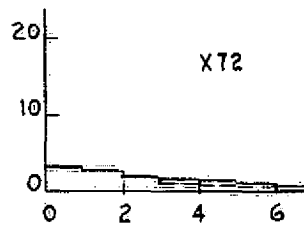
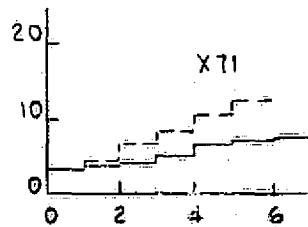


Figure 6-3(b). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



NOTE:

- R63 - R67 = 1.0
- R63, R65, R66 = 1.0  
R64 = 5.0, R67 = 50.0

SIGNAL CYCLES

Figure 6-3(c). - Concluded.



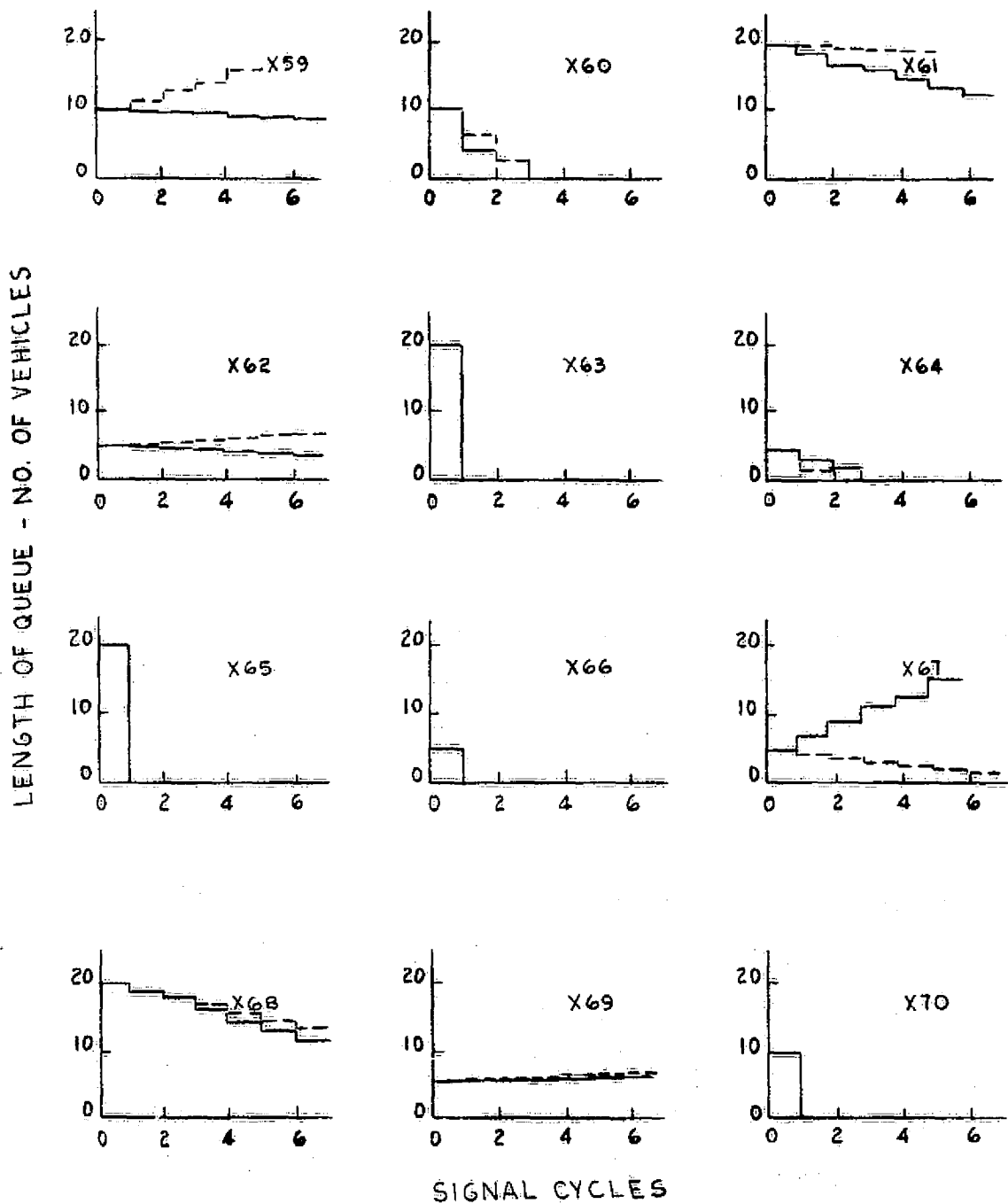


Figure 6-4. - Dissipation of vehicle queues - 11-1 p.m. Secor-Dorr-Byrne - unconstrained links.

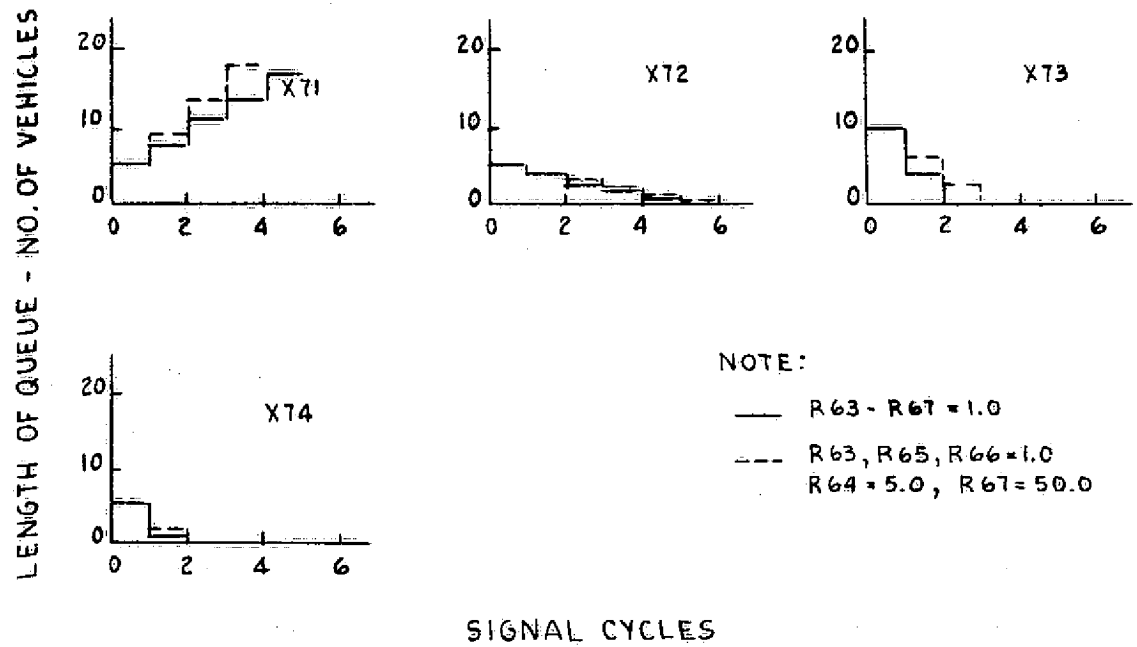


Figure 6-4(a). - Continued.

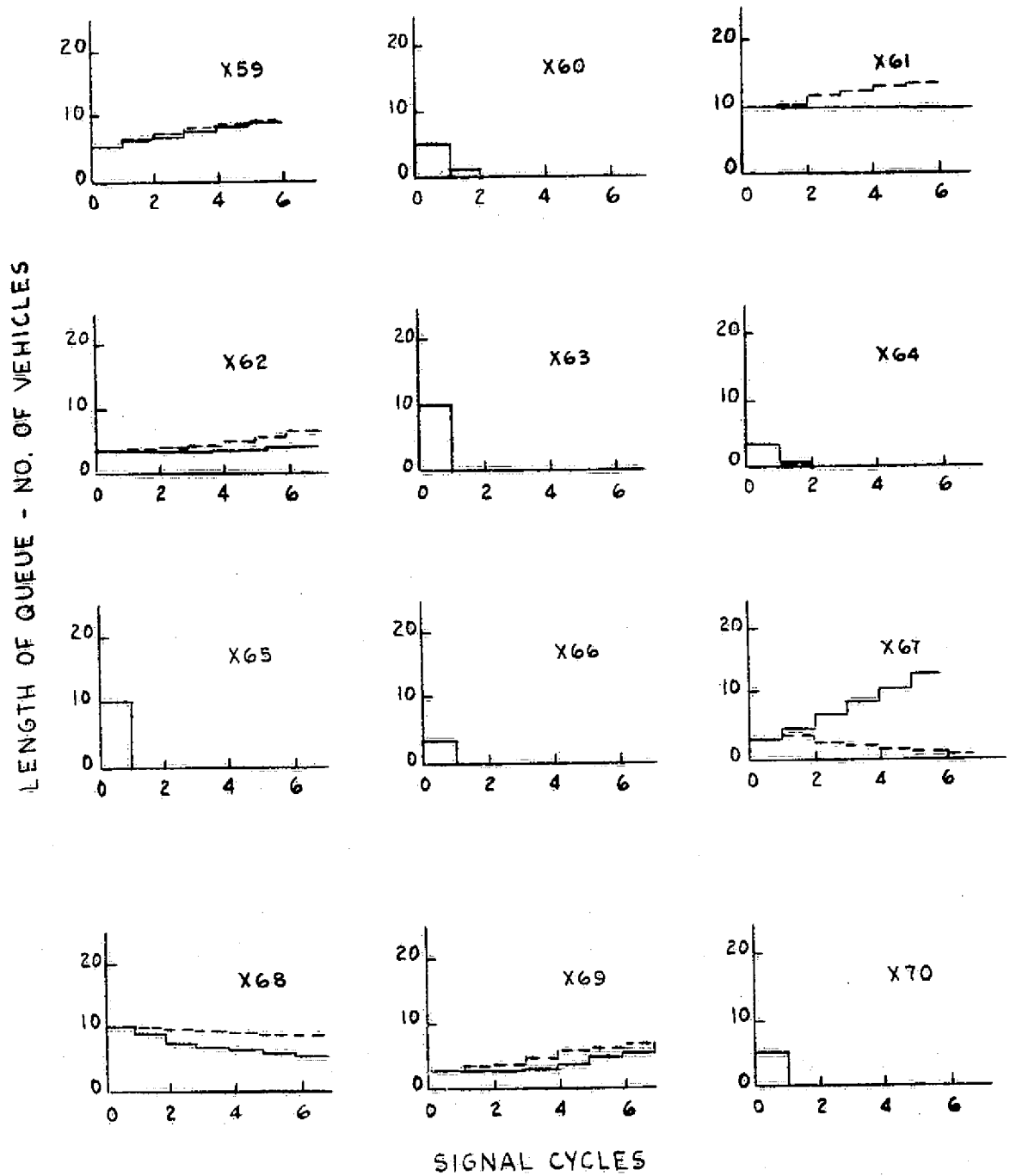
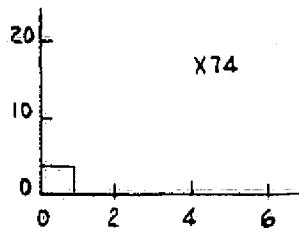
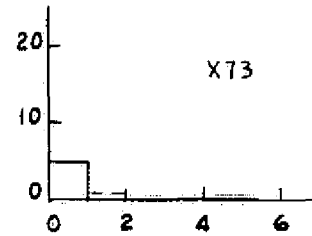
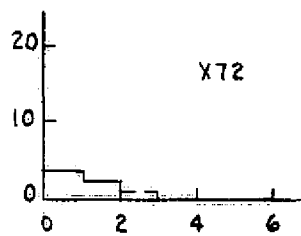
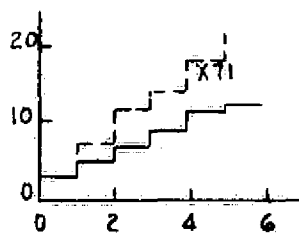


Figure 6-4(b). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



NOTE:

- $R_{63} - R_{67} = 1.0$
- $R_{63}, R_{65}, R_{66} = 1.0$
- $R_{64} = 5.0, R_{67} = 50.0$

SIGNAL CYCLES

Figure 6-4(c). - Concluded.

weighting effectively eliminates the congestion experienced for the left turn lane from Dorr-Byrne (X67). However, queue build-up occurs for all right turn traffic lanes (X59, X69, X71). Similar data are presented in figures 6-5 to 6-5(c) for the 3 to 6 p.m. interval. These results also indicate that the left turn queues (X64, X67) decrease rapidly and are further prevented from increasing to congestive levels. The external right turn queues (X59, X71) increase considerably and may not clear until the end of the time interval or whenever the traffic flow decreases. The external queues (X68, X69) remain nearly constant, and the waiting time long, forcing the drivers to wait for several signal cycles before proceeding through the intersection. For equal state weighting, the left turn queue (X67) builds up considerably and probably cannot clear. The limitation is that this link will eventually saturate and additional vehicles cannot be discharged into the link.

For both state weightings, the right turn traffic increases to unreasonable levels since the departure rates for the respective queues is lower than the arrival rates. This problem is also apparent for the complete network where effective traffic control is not possible unless right turn traffic is permitted for special situations.

6.1.1. Constrained links. - The analysis was further extended by assuming constrained links between the two intersections (#478-497). The study was academic. However, it proves that the model can monitor and limit the allowable vehicle queue lengths. Whenever a preset limit was achieved, the departure rate of the feeding vehicles was reduced to zero and the selected queue lengths could not increase beyond the specified limits.

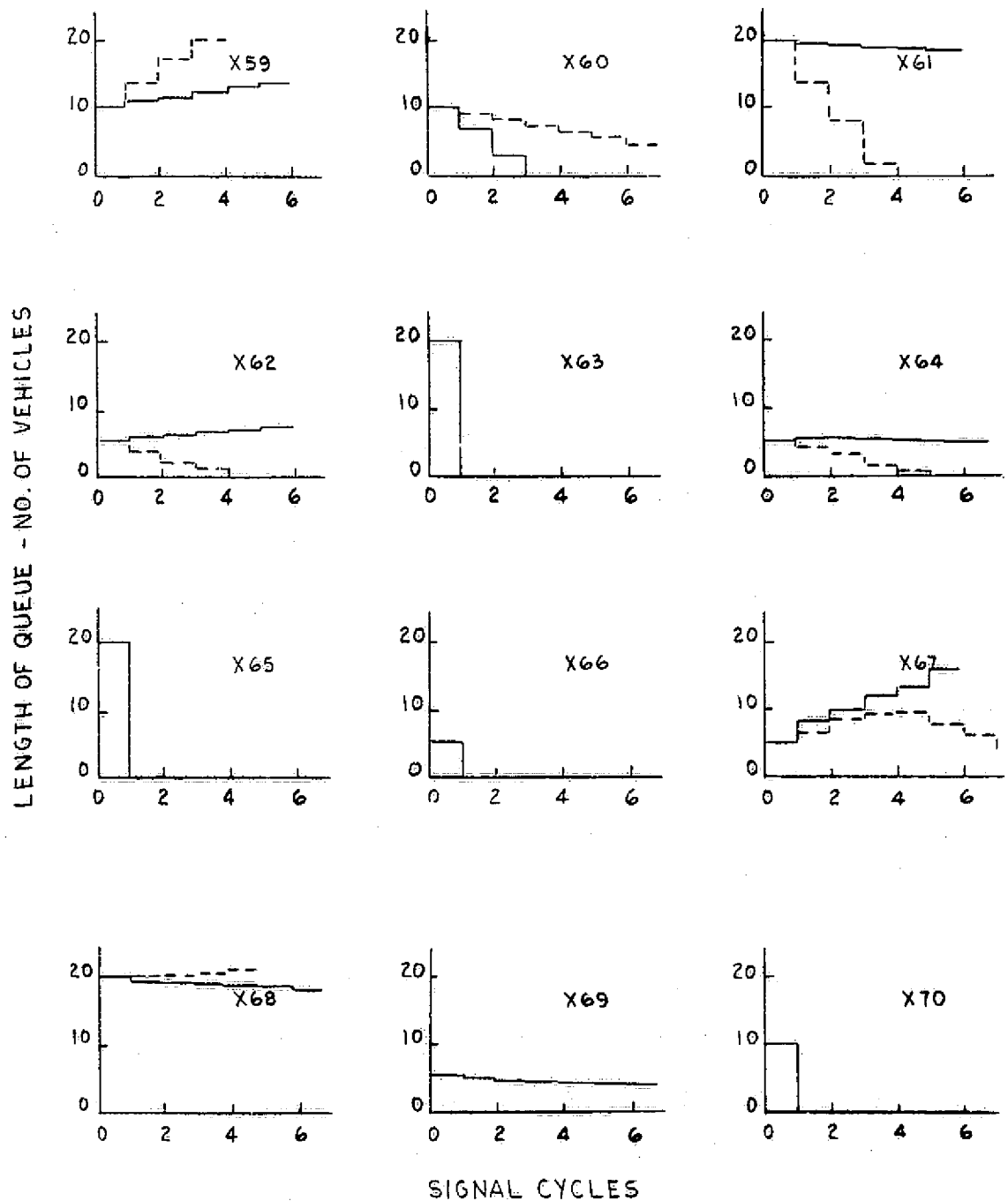
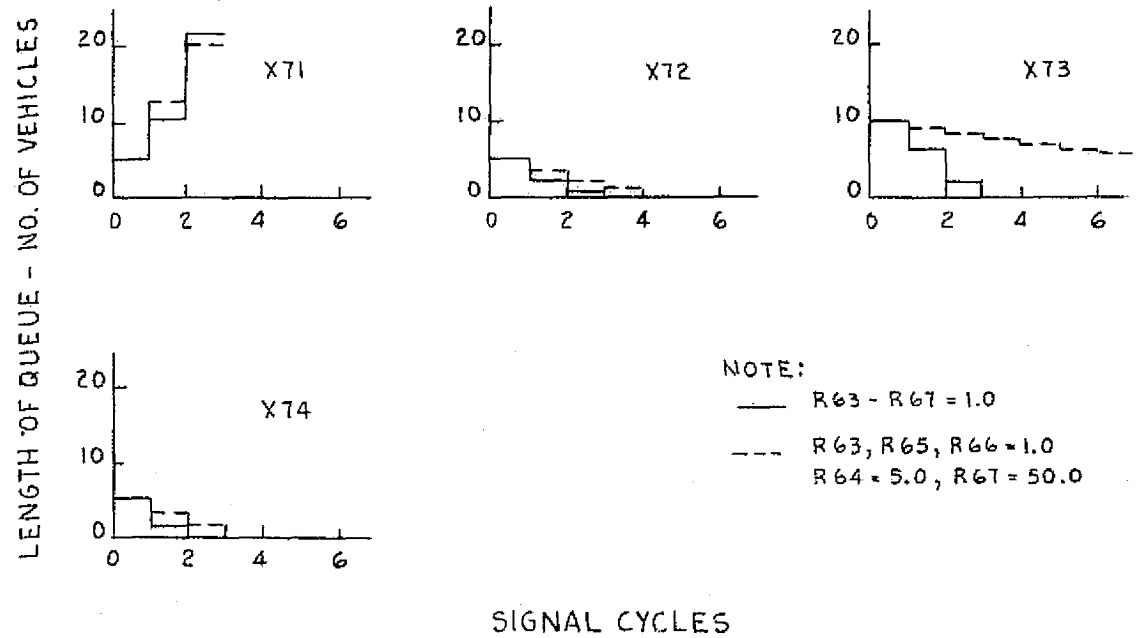


Figure 6-5. - Dissipation of vehicle queues - 3-6 p.m. Secor-Dorr-Byrne - unconstrained links.



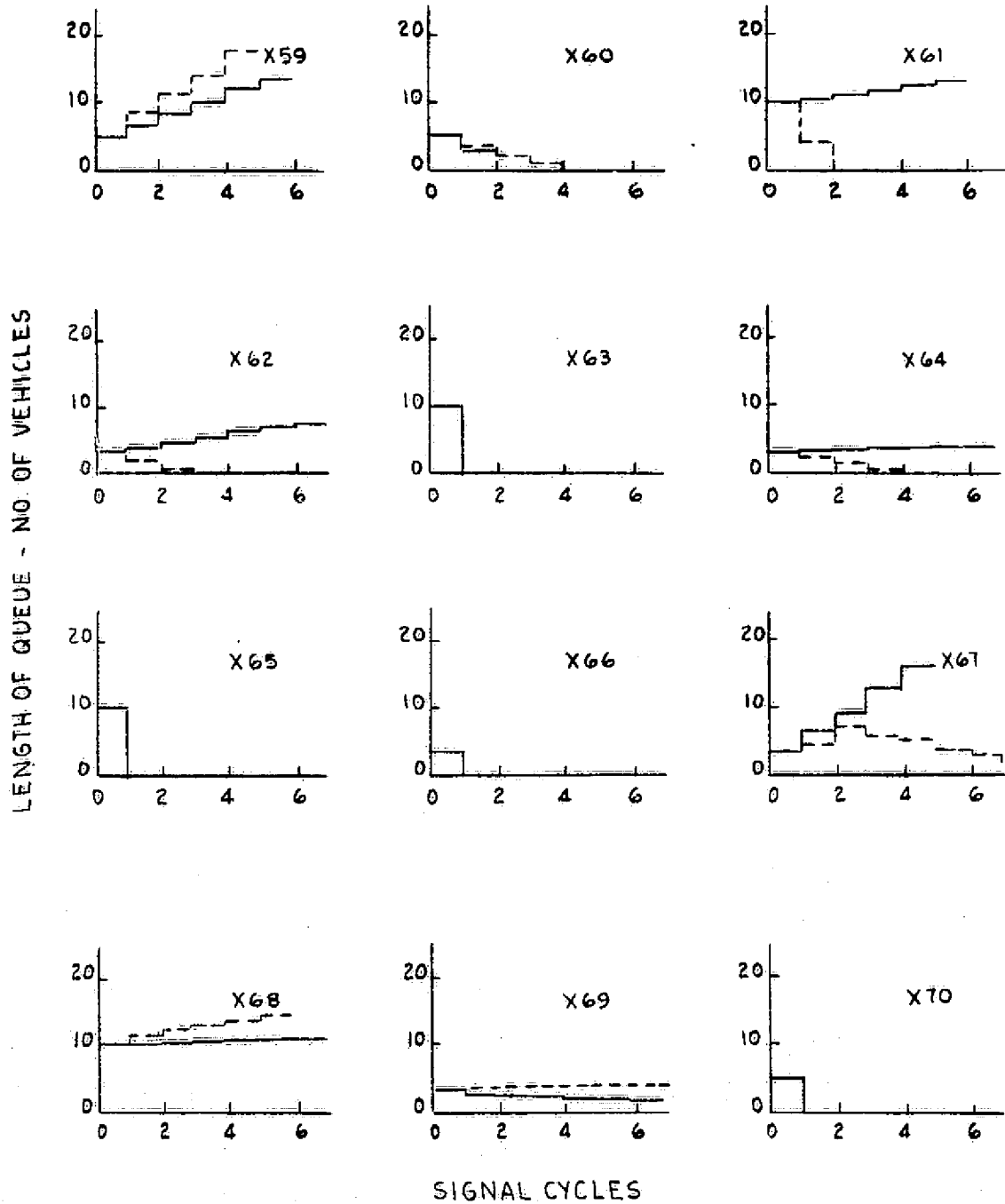
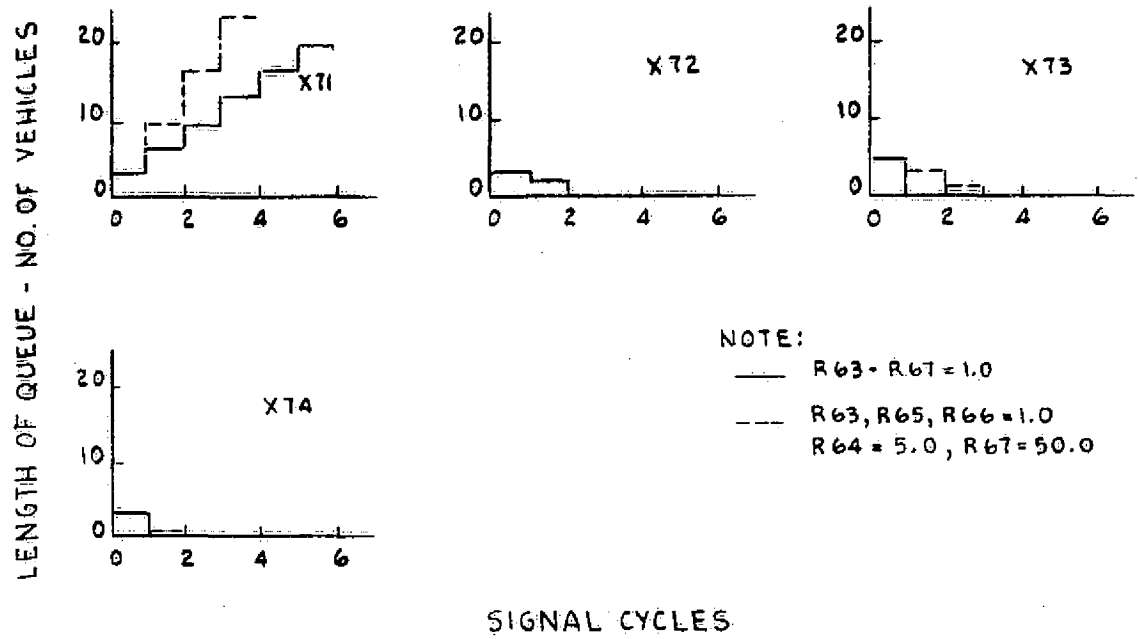


Figure 6-5(b). - Continued.





The effects were only demonstrated for the 3 to 6 p.m. interval for both equal and unequal state weighting. The signal settings and phasing for this condition are illustrated in table 6-2. The table indicates the magnitudes of the signal splits derived for both performance indices. It can be observed that the weighting of the left turn queues does not vary the signal setting significantly since the constraints are effective for both indices. The lower portion of table 6-2 illustrates the phasing of the traffic signals for both intersections. To accommodate the heavy left turn traffic, the E-B Dorr (at Byrne) and W-B (at Secor) traffic was stopped to permit the left turn traffic to proceed. A phase lead-lag approach could also be used; whereby the E-B Dorr (at Byrne) and W-B (at Secor) traffic will be stopped to permit the left turn traffic to proceed through the intersection. At the completion of the green band, traffic in both directions can be resumed. The dissipation of the queues is illustrated in figures 6-6 to 6-6(c). From these results it can be concluded that the behavior of most vehicle queues follows a similar pattern for both initial queue lengths and performance indices. A considerable improvement for the Dorr-Secor left turn traffic (X67) was obtained for the weighted performance index. The Byrne-Dorr (X59) and Secor-Dorr (X71) queues increase and cannot be cleared until the arrival rates of the vehicles decrease below the departure rates. The magnitudes of the signal splits can also be forced to preselected levels to assure that all queues clear eventually. Optimum results cannot be achieved for this condition.

## 6.2 Optimization Procedure

The optimization of the traffic control variables and evaluation

TABLE 6-2. - OPTIMAL CONTROL SETTINGS, 3-6 P.M.

[Intersections 478-497 constrained links]

$$R63 - R67 = 1.0 \quad R63, 65, 66 = 1.0$$

$$IQ = 0.5 \quad IQ = 1. \quad R64 = 5., R67 = 50.$$

## No. 478

Northbound - Byrne	0.223	0.199	0.215
Westbound - Dorr	.677	.701	.685
Eastbound - Dorr	.121	.125	.109
Left turn - Dorr-Byrne	.556	.576	.576

## No. 497

Eastbound - Dorr	.536	.558	.571
Westbound - Dorr	.154	.171	.166
Left turn - Dorr-Secor	.382	.387	.405
Southbound - Secor	.364	.342	.329
Northbound - Secor	.164	.142	.129
Left turn - Secor-Dorr	.200	.200	.200
Performance cost	279.8	401.1	447.1

## NO. 478

BYRNE NB		.215
DORR WB	.685	
DORR EB	.109	
DORR-BYRNE LT	.576	

## NO. 497

SECOR NB		.129
SECOR SB		.329
SECOR-DORR LT		.200
DORR EB	.571	
DORR WB	.166	
DORR-SECOR LT	.405	

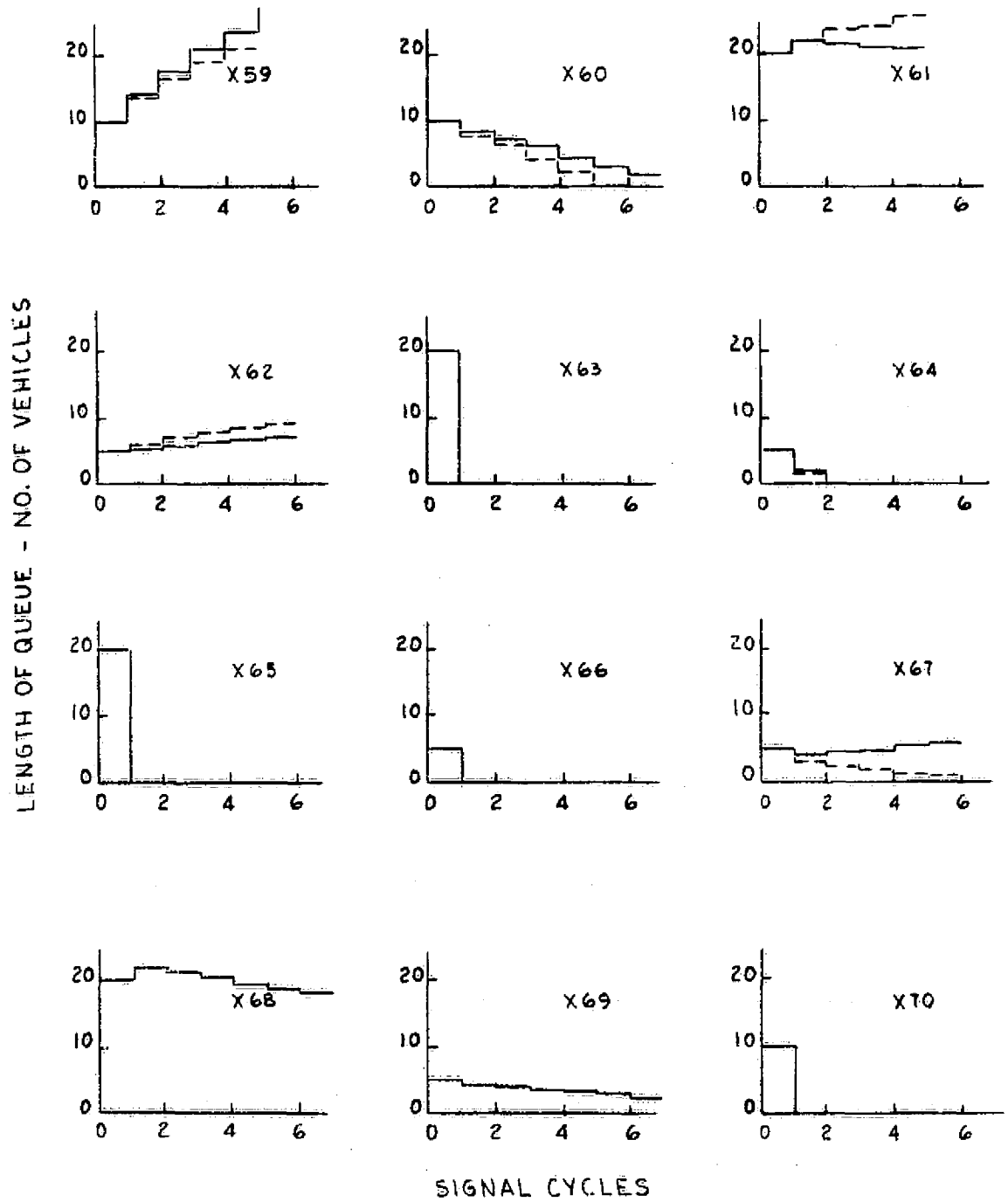
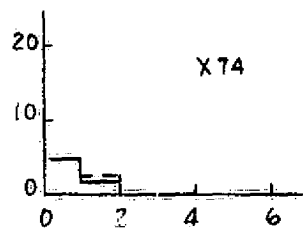
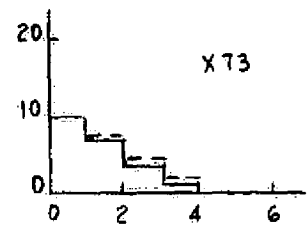
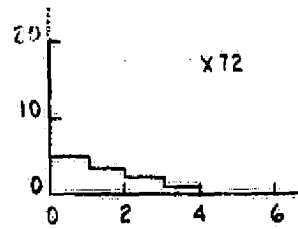
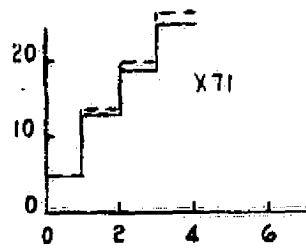


Figure 6-6. - Dissipation of vehicle queues - 3-6 p.m., Secor-Dorr-Byrne - constrained links.

LENGTH OF QUEUE - NO. OF VEHICLES



NOTE:

—  $R_{63} - R_{67} = 1.0$

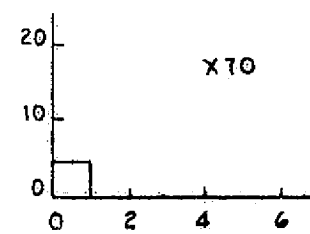
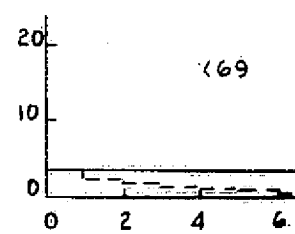
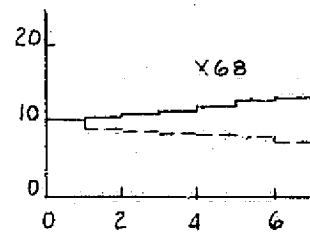
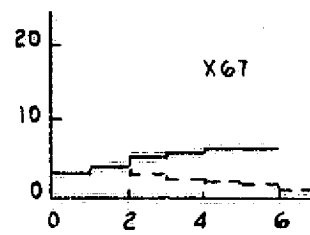
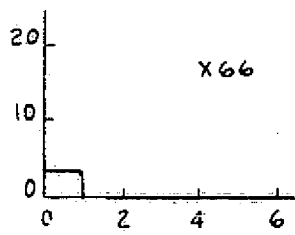
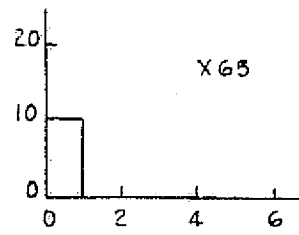
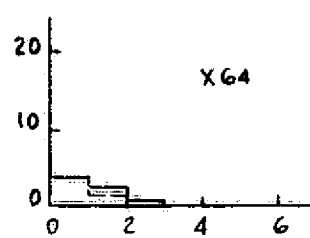
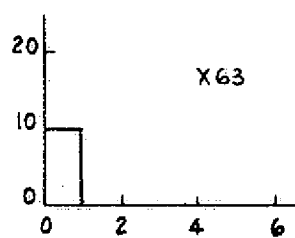
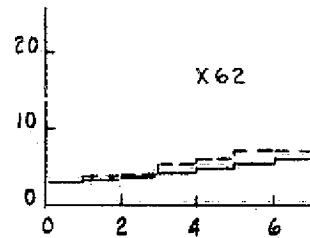
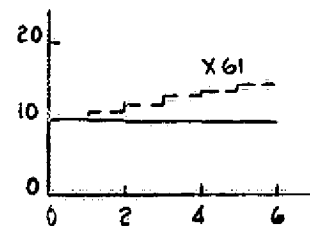
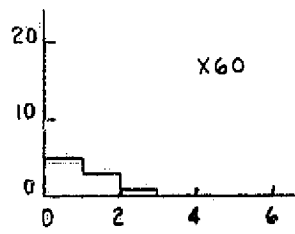
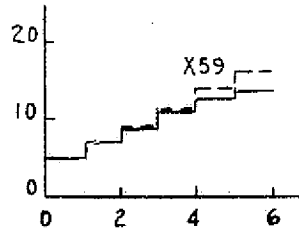
---  $R_{63}, R_{65}, R_{66} = 1.0$

$R_{64} = 5.0, R_{67} = 50.0$

SIGNAL CYCLES

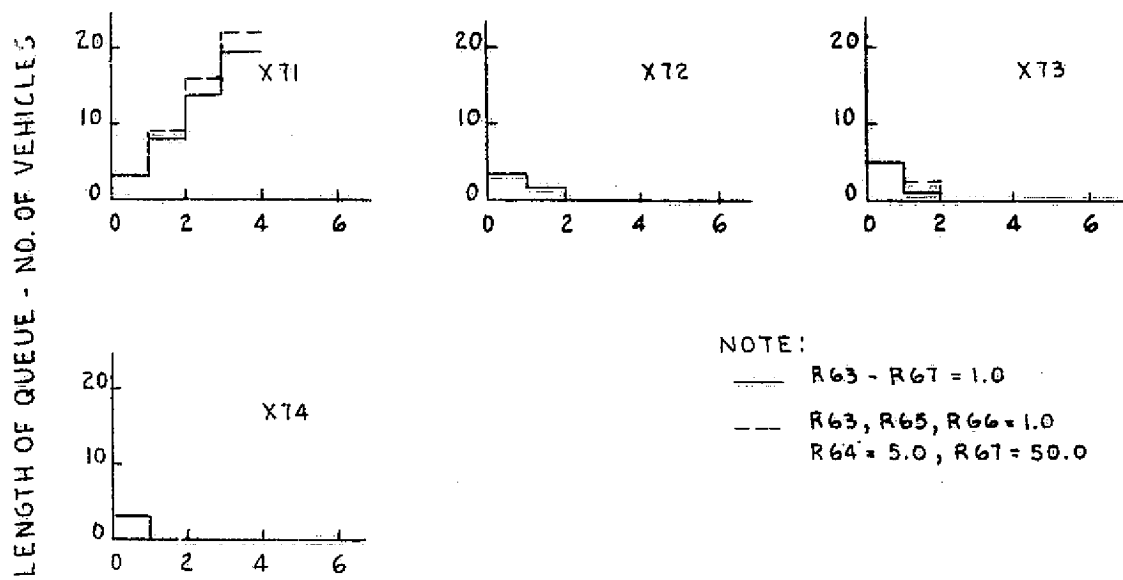
Figure 6-6(a). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 6-6(b). - Continued.



## SIGNAL CYCLES

Figure 6-6(c). - Concluded.

of the behavior of the vehicle queues was performed on an IBM 360 digital computer. Several digital computer programs were developed to perform these functions. The call program, presented in figure B-1, initializes the main program. This program includes the dimensions of the control variables, convergence criterion, maximum number of iterations and initial approximations for the control variables. The program calls an external program function TSPC (fig. B-2) and the IMSL subroutine ZXPOWL (21). The function TSPC is the mathematical description of the selected intersections. The optimization procedure proceeds through the algorithm to evaluate the optimal values for the control variables. Intermediate values are listed as the Zangwill-Powell algorithm searches for the minimum values. If the optimization program cannot find an absolute minimum, error criteria are printed to indicate the failure. For the relatively simple two intersection model, the procedure determines the minimum values within a reasonable computing time. For many intersections, such as the two traffic models presented in chapter VII, the optimization procedure may not determine a set of minimum control settings. The algorithm provides an error criterion to identify the difficulty encountered in the procedure. Due to the large dimensionality of the traffic network, it is impossible to visualize a pictorial representation of the multidimensional model. For the error criterion IER (130), usually a slight shift in the values for the control variables will generally continue the optimization process until a minimum value is found.

The program that computes the behavior of the queues is presented in figure B-3. This program is a duplication of the function subprogram including the pertinent output information to describe the dissi-



pation of the queues. Through the NAMELIST option, the control variables, initial queue lengths, vehicle inflow, service rates, and state and control weighting factors can be modified.

### 6.3 Conclusions

The previous two sections presented the results for a simple two intersection network. The objective of the analysis was to demonstrate a method that will eliminate the internal congestion for the intersections. A model describing the behavior of the vehicle queues was formulated and optimized to derive the optimal signal settings. The clearance of the internal queues (X63 - X67) could be accomplished by increasing the state weighting factors for these critical queues. The analysis was performed for both unconstrained and constrained links.

The results of the analysis indicate that for an equally weighted performance index and unconstrained links most of the queues are well-behaved. The right and left turn queues build up considerably and may not clear until the inflow to the network is reduced. For an unequally weighted performance index ( $R64 = 5.$ ,  $R67 = 50.$ ), the left turn queues (X64, X67) were cleared within several signal cycles. This refinement can be extended to other critical queues to assure that these states eventually clear. This situation offers a compromise solution to an otherwise uncontrollable traffic problem. An alternate approach is to include control weighting factors ( $R7 - R8a \neq 0$ ) and force the selected signal settings to desired levels. The difficulty is that all traffic directions must be given a green band within the total cycle time.

Similar results were obtained for the constrained link conditions.

The inflow to the internal links was reduced whenever the maximum storage capacity was exceeded. By constraining these links, the left turn queues cannot build up beyond set limits. For the equally weighted performance index, the Dorr-Secor (X67) left turn traffic builds up to a preset level; whereas for the unequal weighting the queue dissipates rapidly. Due to the limited inflow to the constrained links, some of the external links increase more rapidly.

Summarizing the results, it can be shown that for the two intersection model, the critical queues can be cleared and maintained at uncongested levels within several signal cycles. This situation can only be achieved at the expense of increasing external queue lengths.

## CHAPTER VII. SIMULATION RESULTS FOR TRAFFIC NETWORKS

The concepts of the proposed traffic theory were applied to two actual traffic networks. The models were formulated in a manner prescribed by the present control patterns. The details of the present control philosophy were maintained as much as possible. The actual changes for the proposed system are minimal; such as optimal settings for selected left turns and right turns for special situations. These changes are included to improve and facilitate the movement of the traffic flow and prevent congestion throughout the networks. The results indicate that with the proposed signal settings, the vehicle queues effectively dissipate within a reasonable number of signal cycles and prevent congestion for normally heavy traffic conditions. The present traffic signal settings implemented by the Toledo Traffic Engineering Division are presented for comparison with the proposed signal settings. The Toledo signal settings are appropriate to efficiently control the traffic flow within the networks. However, several critical queues increase to congestive levels and may not clear until the traffic flow is reduced.

The subnetworks are part of a large traffic network proposed for controls analysis by the Traffic Engineering Division. Computerized traffic control must be contemplated for this area over the next several years. The network can be subdivided into three subsystems; from which two models were formulated and optimized to derive the signal settings throughout the networks for each of three time intervals.

### 7.1 Results for Section I

The topology of section I is illustrated in figure 7-1. It consists of an area bounded by Reynolds, Byrne, Dorr, and Hill. The intersections were modeled in a generalized form by allowing traffic flow in both directions (E-W, N-S), right and left turns, whenever applicable. The derivation of the optimal control variables includes the main stream traffic flow and the required left turn signal settings, whenever the traffic flow dictates a variable control setting. In most instances, a constant value is adequate to properly control the left turn queues. The intersections and vehicle queues are numerically identified in figures 7-2 to 7-2(b).

The proposed signal settings, derived from the optimization program, for each of the three time intervals is presented in tables 7-1 to 7-1(a). As mentioned previously, these traffic signal settings effectively control the traffic flow to dissipate the queues within a reasonable number of signal cycles. For the specified inflow conditions to the network boundaries, congestion should be completely eliminated throughout the specified time interval, except for abnormal traffic conditions. The computation of the optimal signal values assumes the validity of the given inflow conditions, intersection service rates and ideal traffic conditions. If these conditions should be altered, reoptimization of the model is necessary to establish a new set of optimal values. However, if the initial guesses are close to the optimal values, optimization can be obtained within a short computing time. Using an IBM 360 computer, the solution can be derived within 500 to 1500 cpu seconds; depending upon the initial approximations for

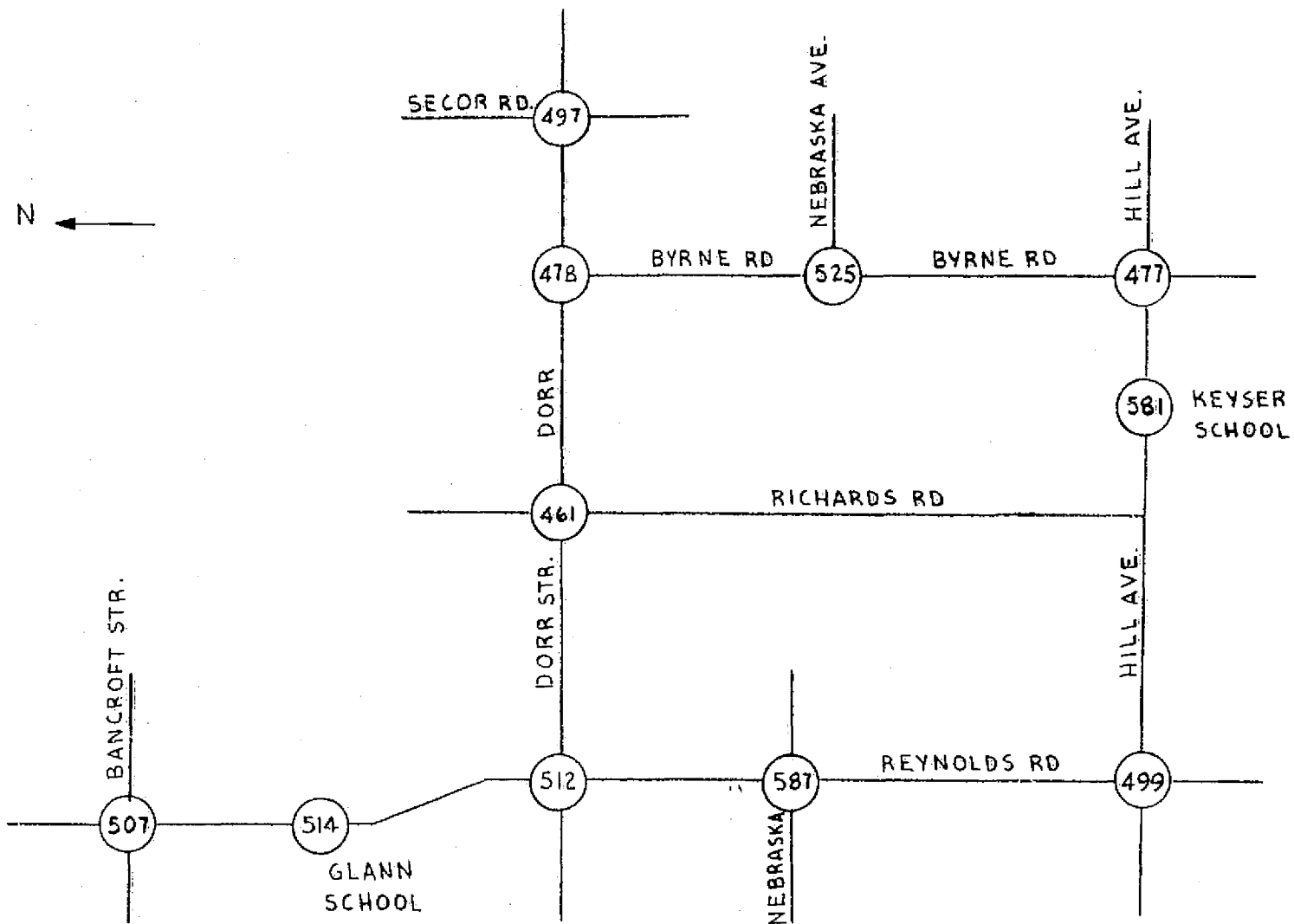
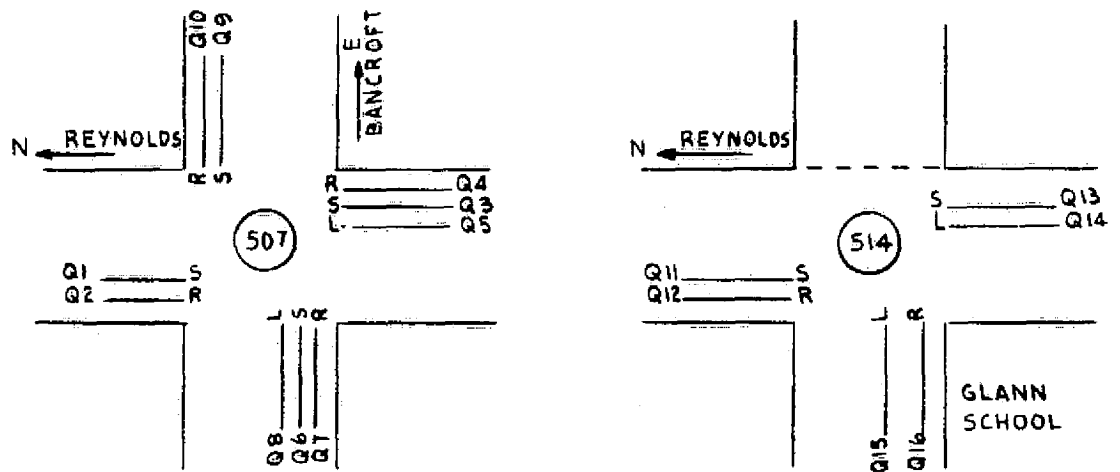


Figure 7-1. - Traffic network - Section I.



NOTE:

S - STRAIGHT  
R - RIGHT TURN  
L - LEFT TURN

○ - INTERSECTION

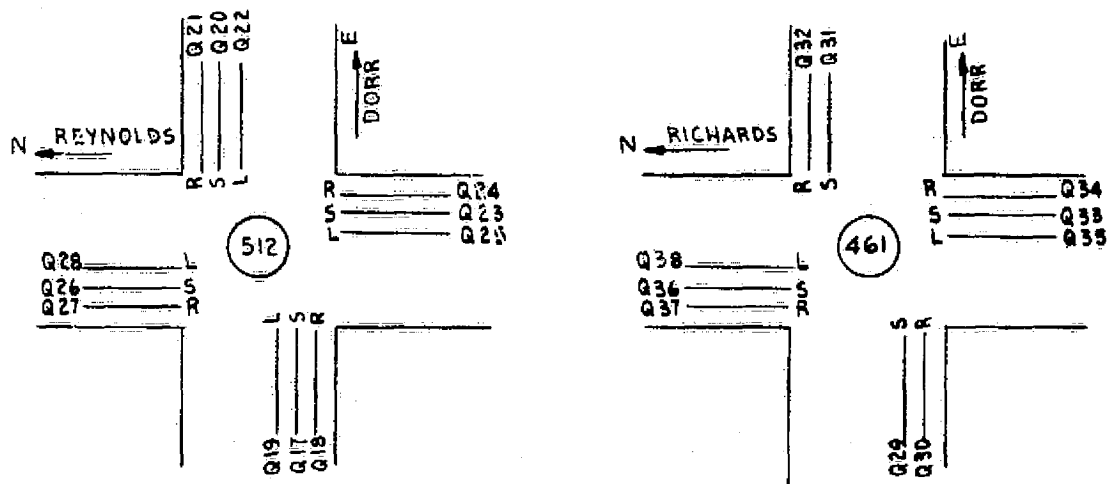


Figure 7-2. - Identification of intersections and queues, Section I.

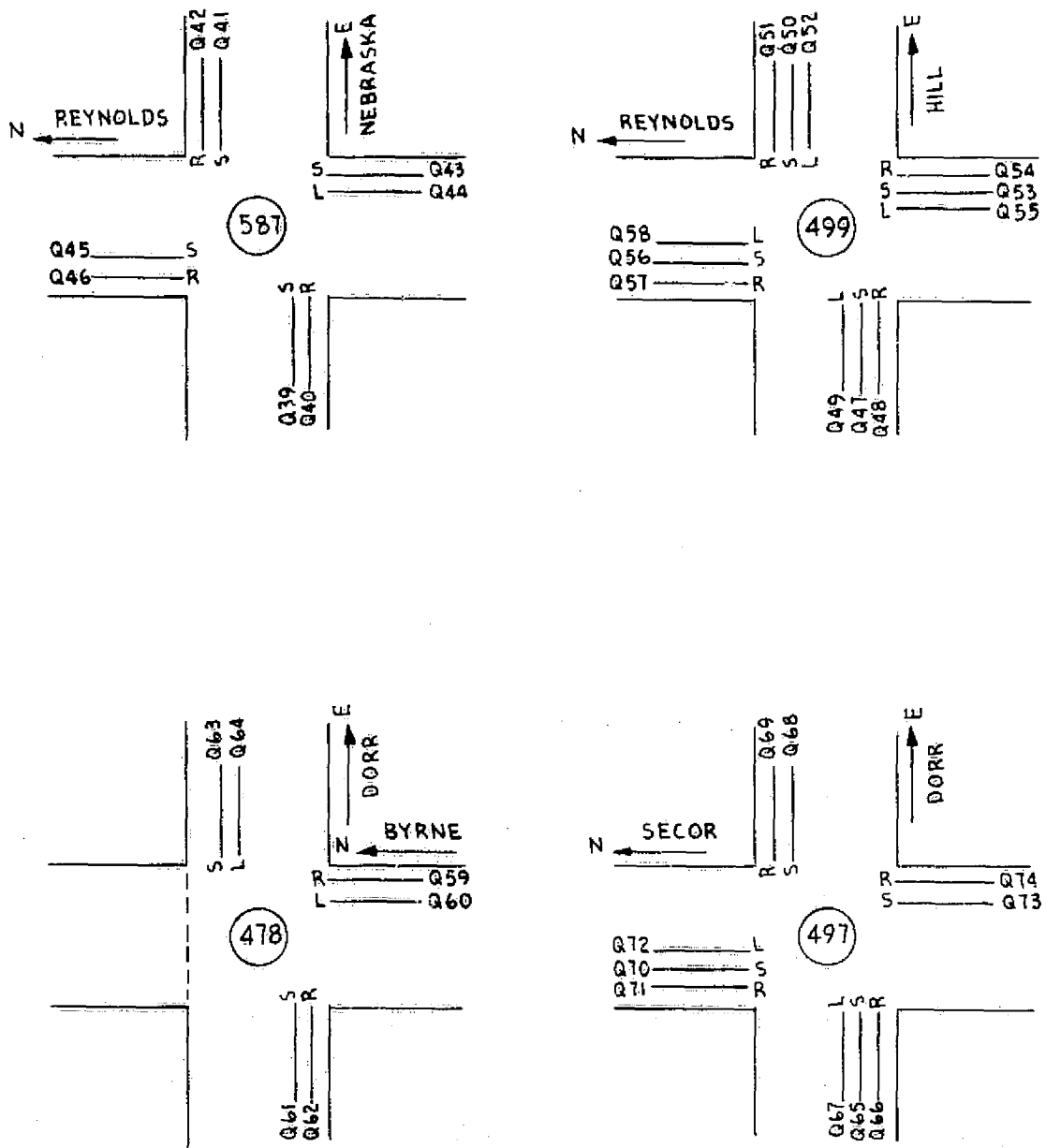


Figure 7-2(a); - Continued.

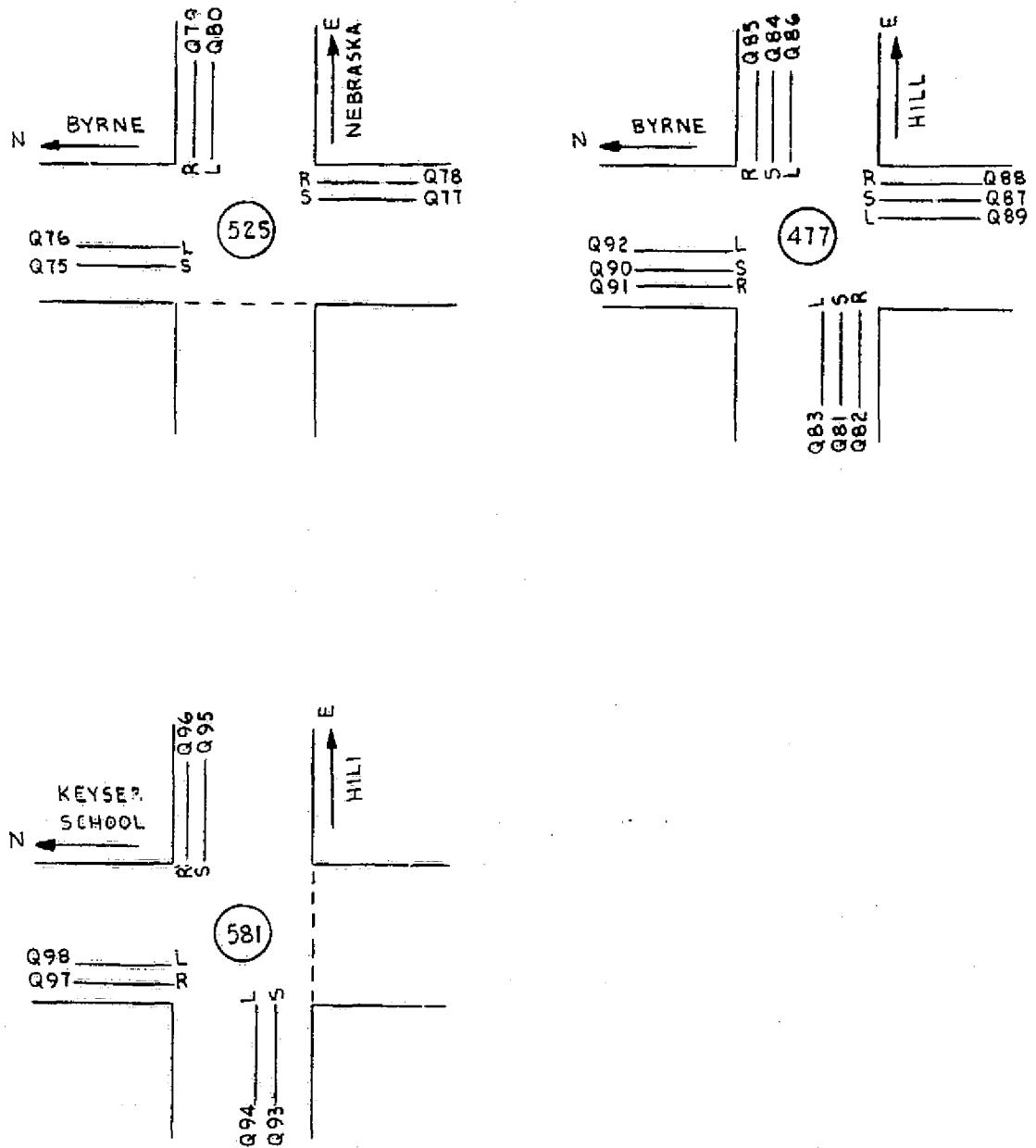




TABLE 7-1. - CONTROL SETTINGS - SECTION I

Control	7-9 a.m.	11-1 p.m.	3-6 p.m.
U1	0.676	0.677	0.587
DEL1	.150	.150	.150
U2	.700	.700	.700
DEL2	.150	.150	.150
U3	.294	.280	.249
U3A	.136	.173	.201
DEL3	.100	.100	.100
U4	.622	.630	.613
DEL4	.150	.150	.150
U5	.700	.700	.650
DEL5	.150	.150	.150
U6	.412	.410	.452
U6A	.152	.150	.150
DEL6	.150	.150	.150
U7	.150	.150	.215
U7A	.350	.360	.442
U8	.220	.220	.201
U8A	.395	.422	.468
DEL8	.150	.150	.150
U9	.678	.677	.600
DEL9	.150	.150	.150
U10	.370	.370	.270
U10A	.112	.112	.175
DEL10	.150	.250	.300
U11	.648	.658	.580
DEL11	.200	.200	.200
P	.514	.640	1.005

## Definition:

U1	Intersection #507 Reynolds
DEL1	Left turn Reynolds-Bancroft WB Left turn Bancroft-Reynolds NB
U2	Intersection #514 Reynolds
DEL2	Left turn Reynolds-Glenn school WB
U3	Intersection #512 Dorr
U3A	Left turn Dorr-Reynolds

TABLE 7-1(a). - CONTROL SETTINGS - SECTION I

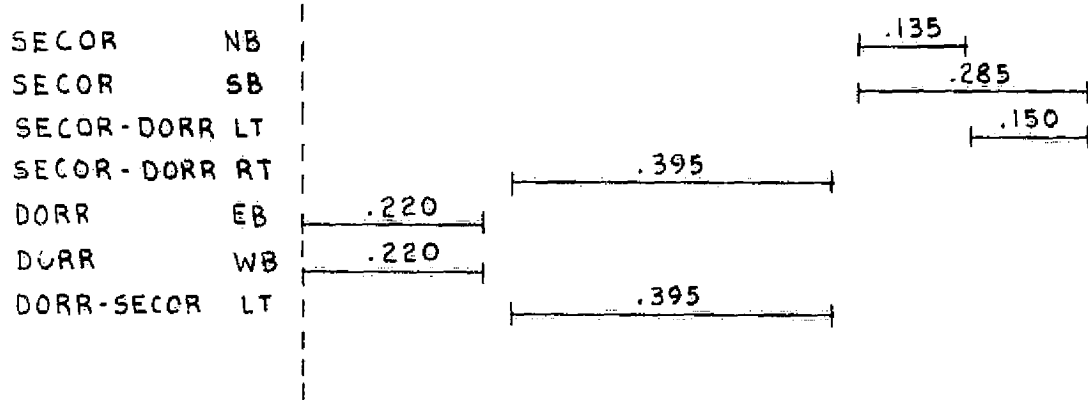
DEL3	Left turn Reynolds-Dorr
U4	Intersection #461 Dorr
DEL4	Left turn Dorr-Richards
U5	Intersection #587 Reynolds
DEL5	Left turn Reynolds-Nebraska WB
U6	Intersection #499 Reynolds
U6A	Left turn Reynolds-Hill
DEL6	Left turn Hill-Reynolds
U7	Intersection #478 Byrne
U7A	Right turn Byrne-Dorr
U7A	Left turn Dorr-Byrne
U8	Intersection #497 Dorr
U8A	Right turn Secor-Dorr
U8A	Left turn Dorr-Secor
DEL8	Left turn Secor-Dorr EB
U9	Intersection #525 Byrne
DEL9	Left turn Byrne-Nebraska EB
U10	Intersection #477 Byrne
U10A	Left turn Byrne-Hill
DEL10	Left turn Hill-Byrne
U11	Intersection #581 Byrne
DEL11	Left turn Hill-Keyser School

the signal settings. Using initial guesses close to the optimal values, the new values are obtained within 150 to 350 cpu seconds. For a simple two intersection problem, the results are obtained within 60 cpu seconds. The approach that can be used to reduce the required cpu time is to calculate the initial approximations from the initial flow conditions.

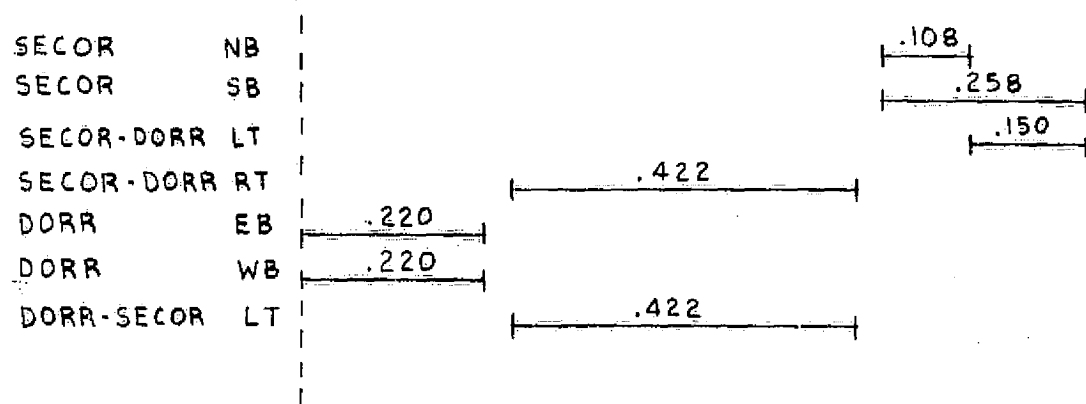
A chart of a typical phasing plan for the traffic signals at each intersection is illustrated in figures 7-3 to 7-3(j). The plan indicates the timing sequence and magnitudes of the control variables (in terms of fractional cycle times) for each traffic signal. The timing sequence was established to coordinate the traffic signals along major thoroughfares. This situation implies that traffic signals along access routes, such as Byrne and Hill, will receive a red band when platoons arrive at a major intersection. Since the models assume heavy traffic flow, vehicles will already be waiting at these intersections. The dead space between the signal splits accounts for delays and amber time. As can be observed from tables 7-1 to 7-1(a) and figures 7-3 to 7-3(j), the differences between the proposed 7-9 a.m. and 11-1 p.m. signal settings are insignificant, except for the Dorr-Reynolds (X19, X22), Dorr-Secor (X67), and Hill-Byrne (X83, X86) left turn traffic. Slightly different signal settings were derived for the 3-6 p.m. traffic since the volume was higher than for the preceding intervals. The signal phasing of most intersections is not complex. As an illustration, consider Reynolds-Bancroft intersection (#507) for the 7-9 a.m. interval. The phase lag approach was used for the Reynolds traffic, whereby the S-B traffic was interrupted to permit the

C-2

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

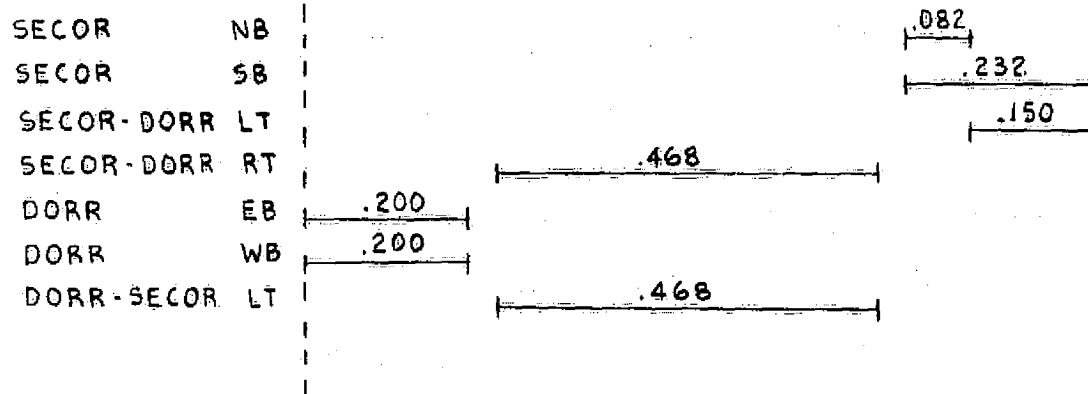
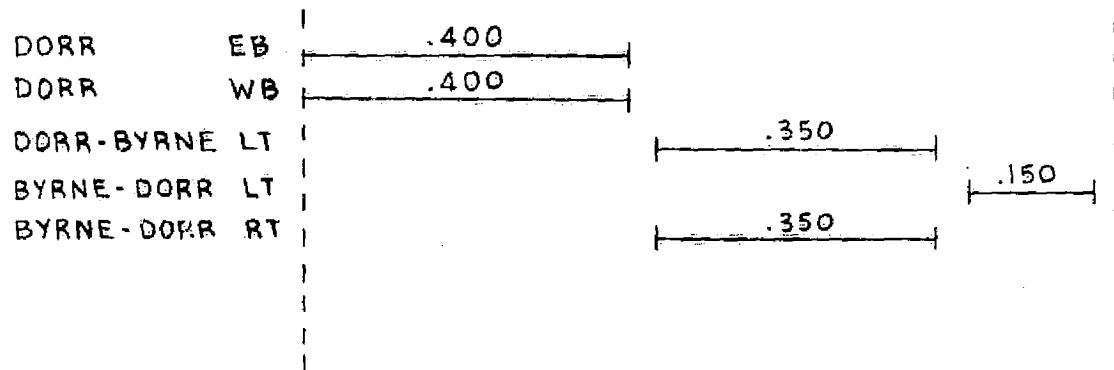
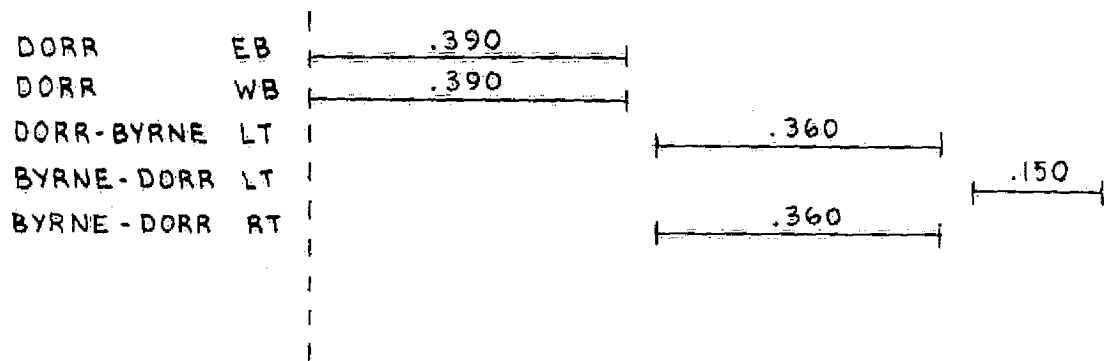


Figure 7-3. - Signal phasing - No. 497, Dorr-Secor.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

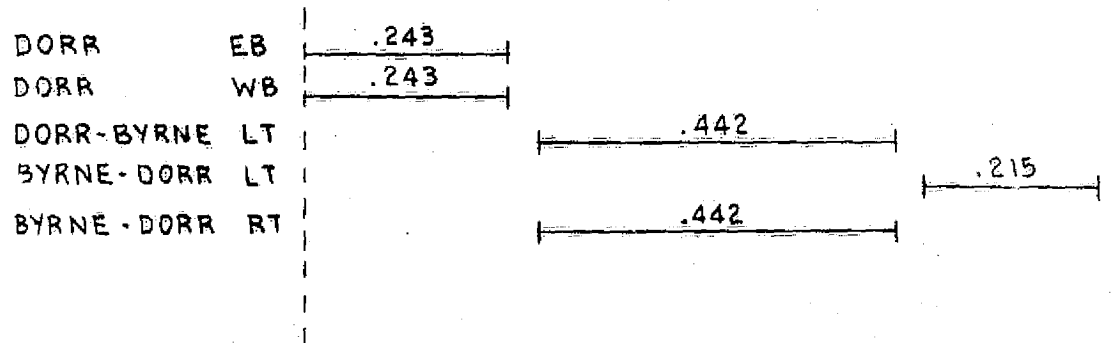
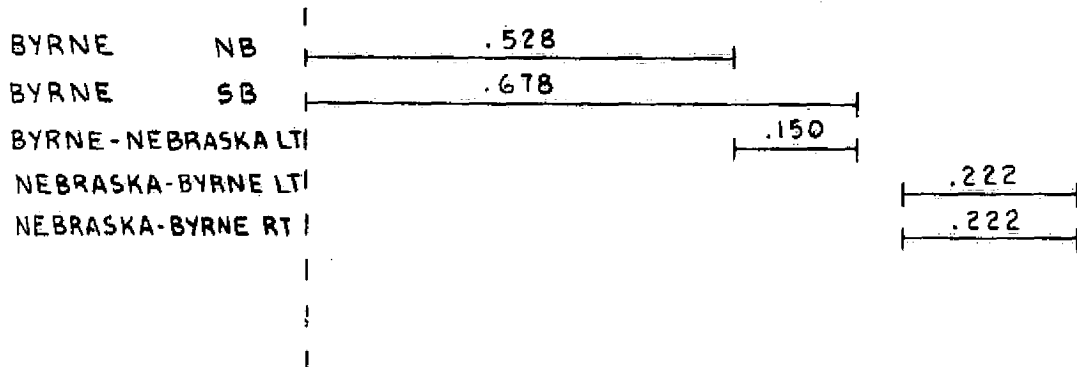
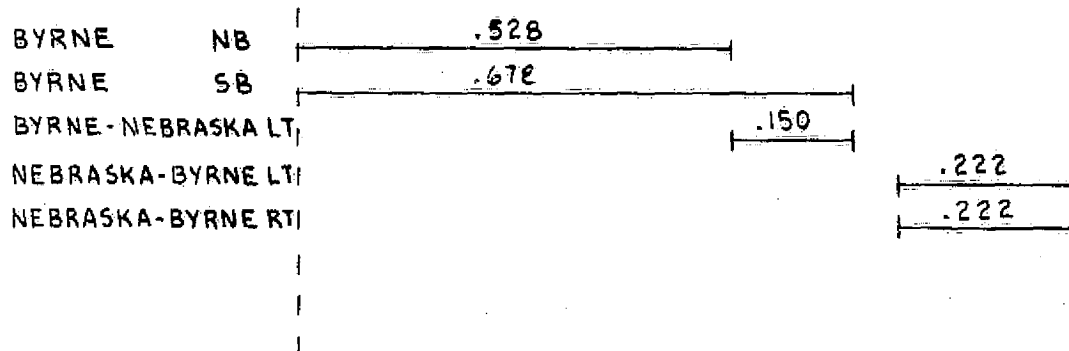


Figure 7-3(a). - Signal phasing - No. 478, Byrne-Dorr.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

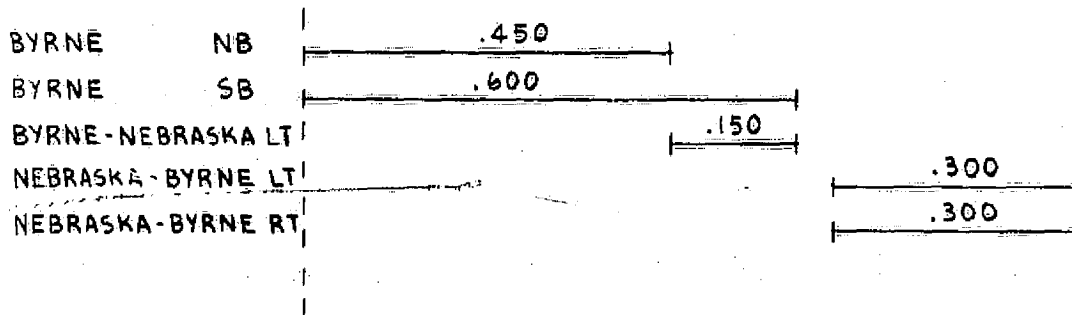
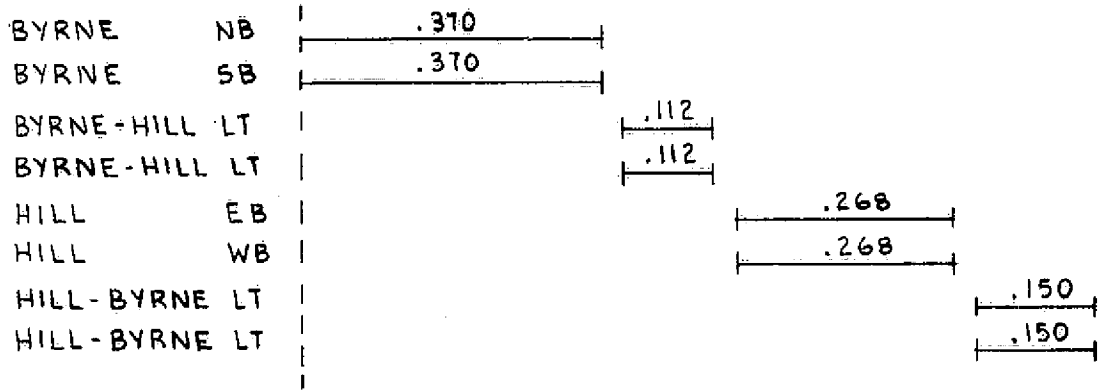
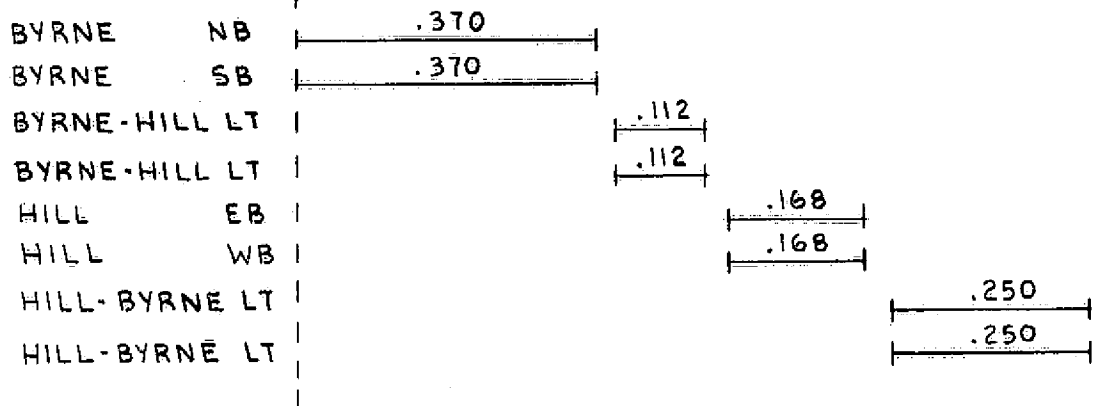


Figure 7-3(b). - Signal phasing - No. 525, Byrne-Nebraska.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

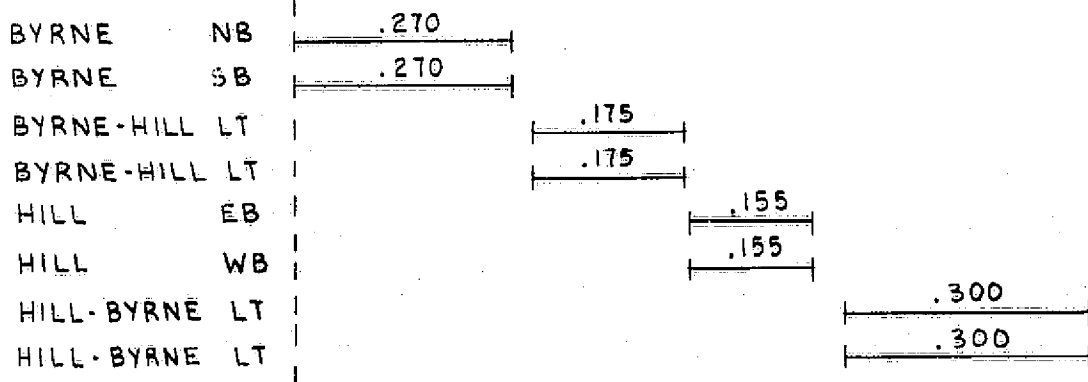
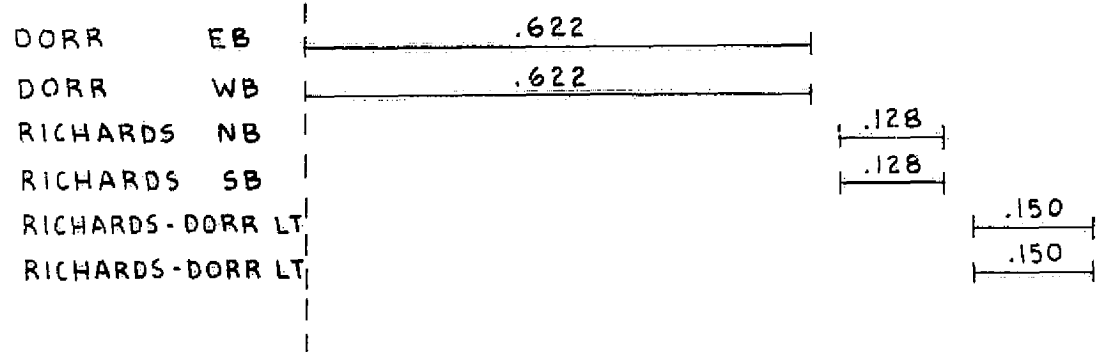
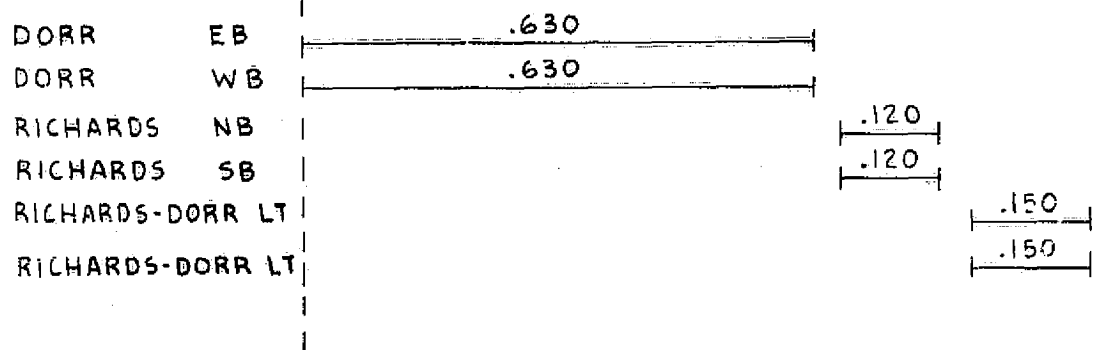


Figure 7-3(c). - Signal phasing - No. 477, Byrne-Hill.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

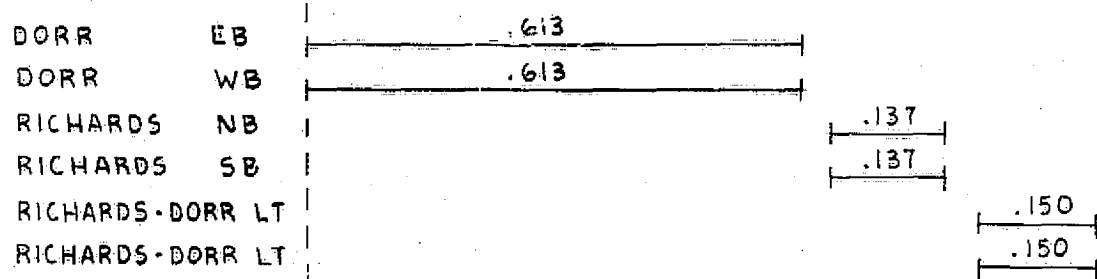
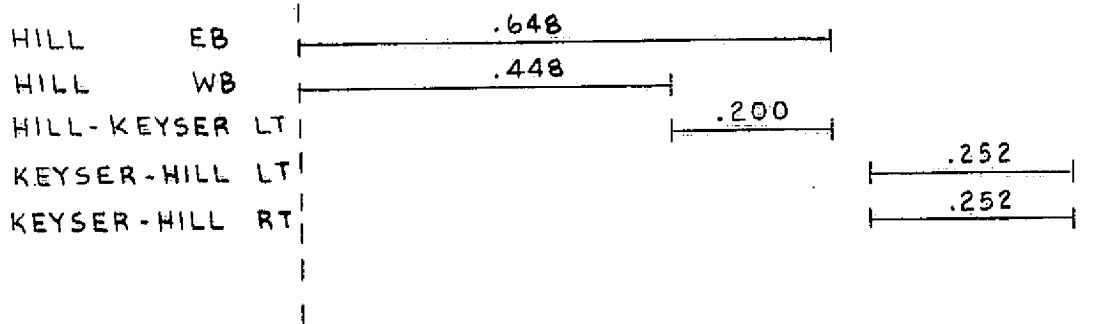


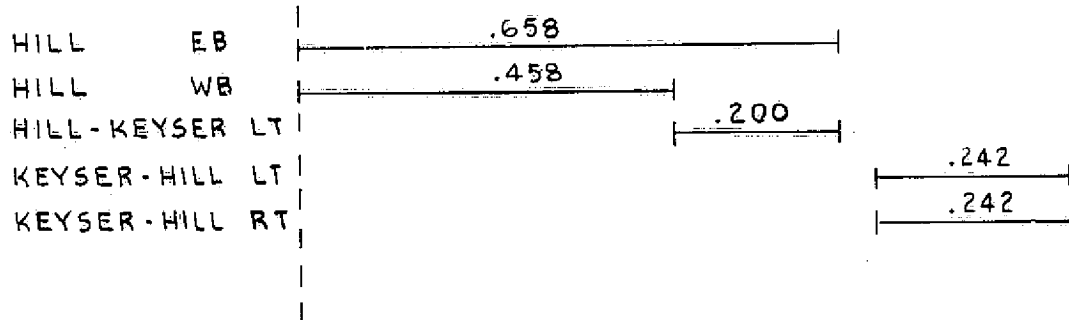
Figure 7-3(d). - Signal phasing - No. 461, Dorr-Richards.



CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

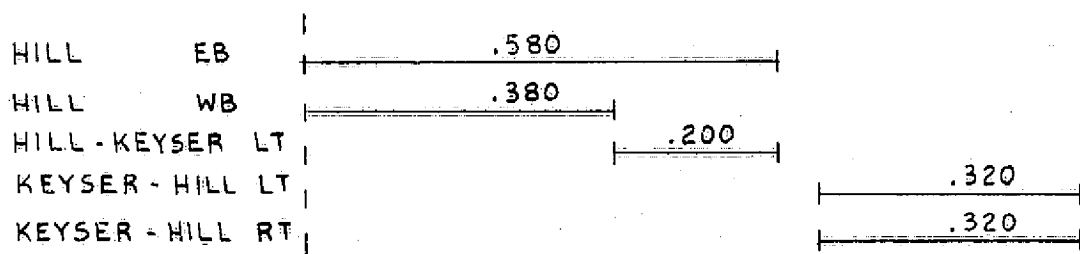
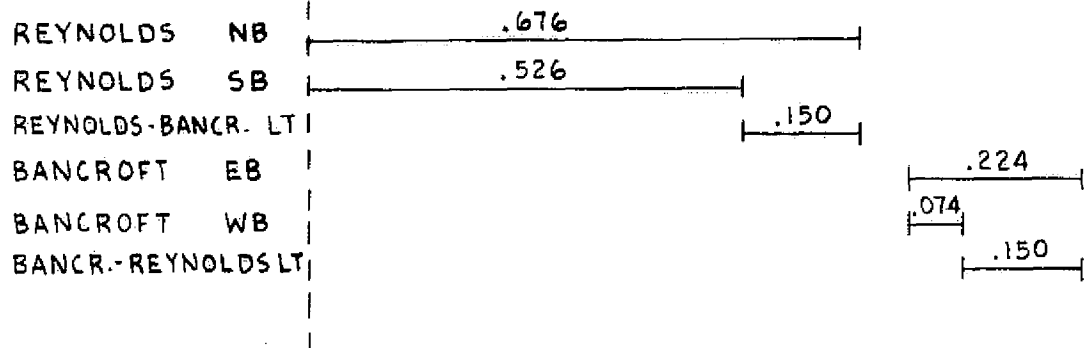
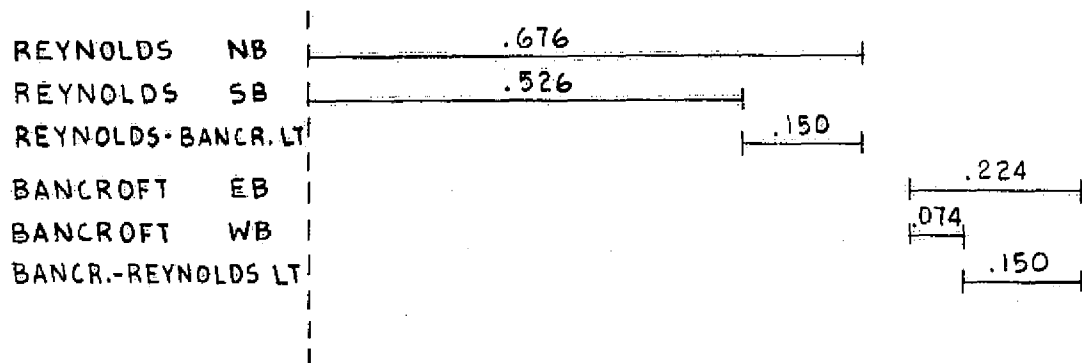


Figure 7-3(e). - Signal phasing - No. 581, Keyser School-Hill.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

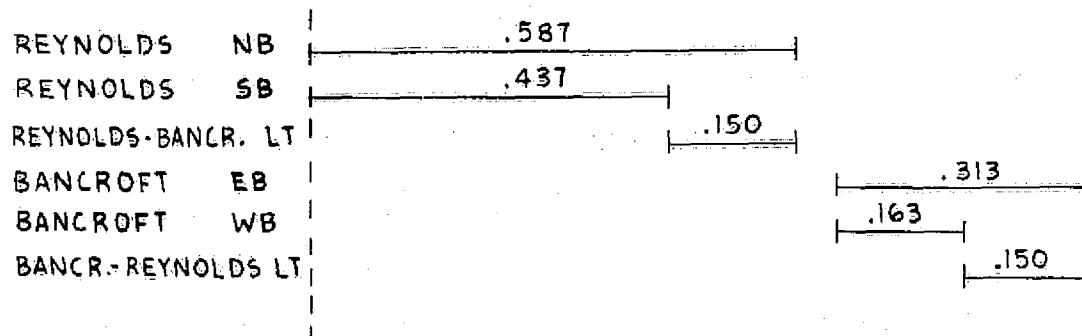
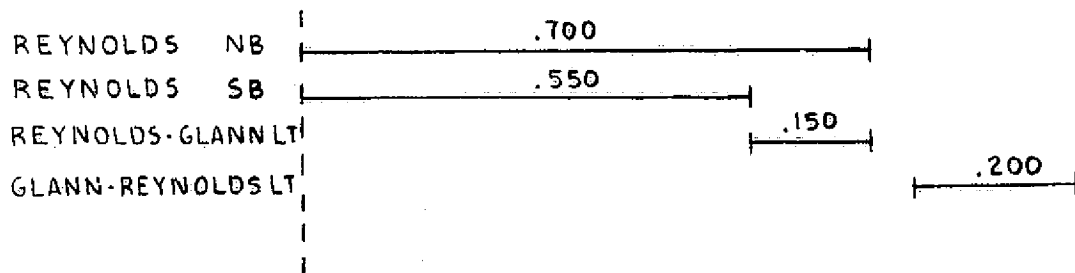
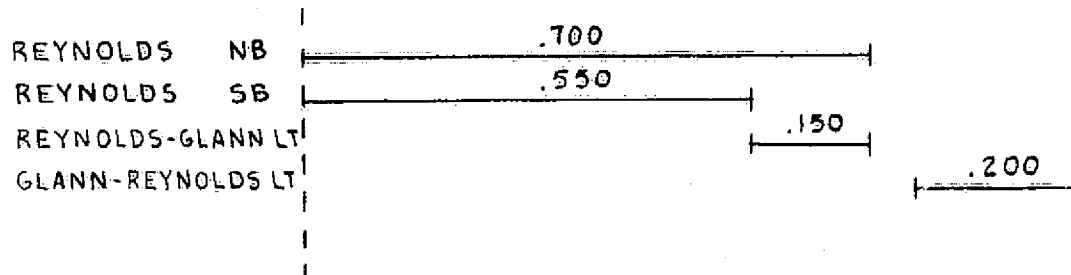


Figure 7-3(f). - Signal phasing - No. 507, Reynolds-Bancroft.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

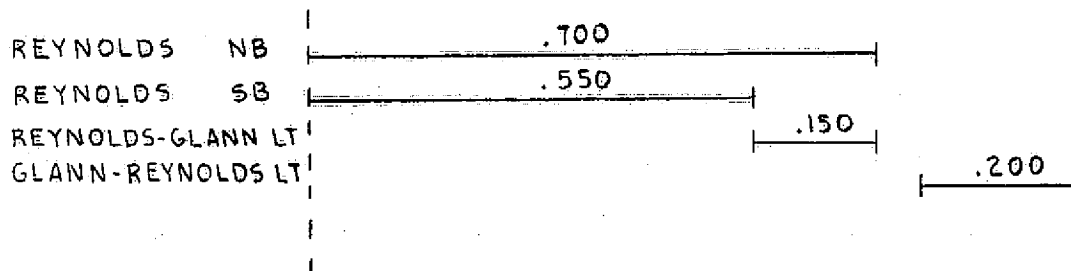
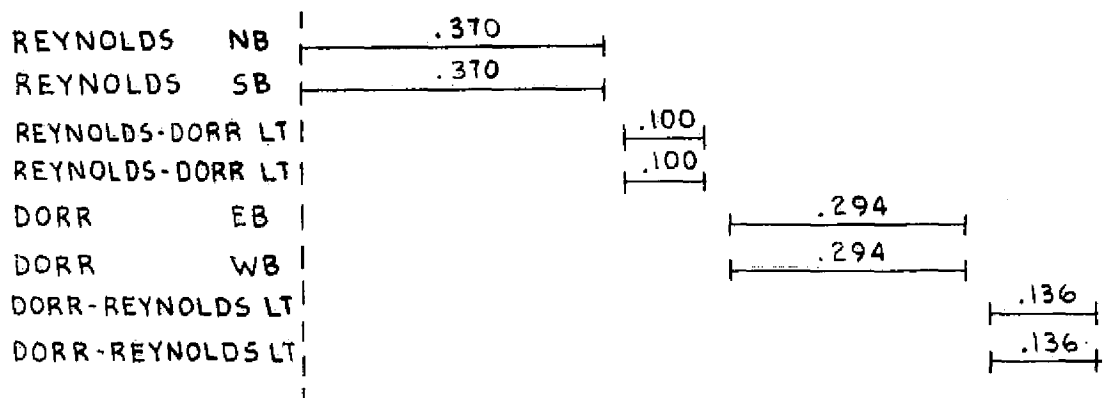
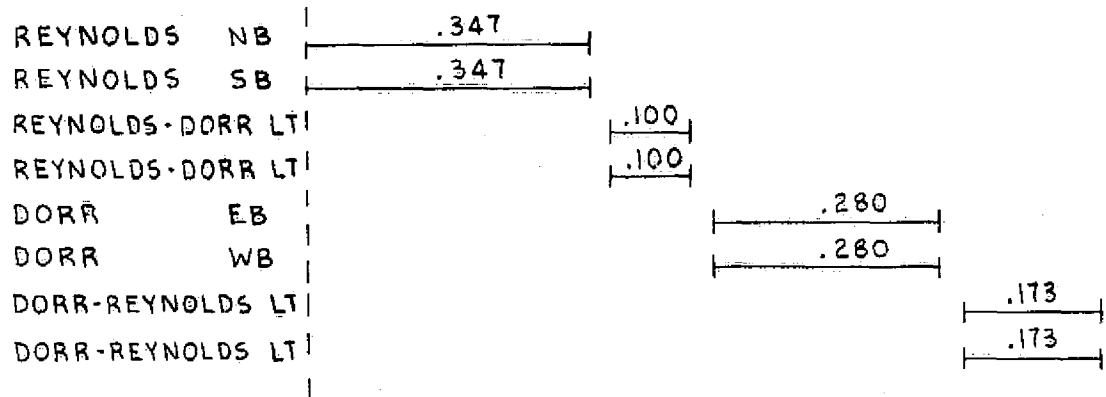


Figure 7-3(g). - Signal phasing - No. 514, Reynolds-Glann School.

CYCLE TIME: 90 SEC.  
TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11 a.m.



TIME OF DAY: 3-6 p.m.

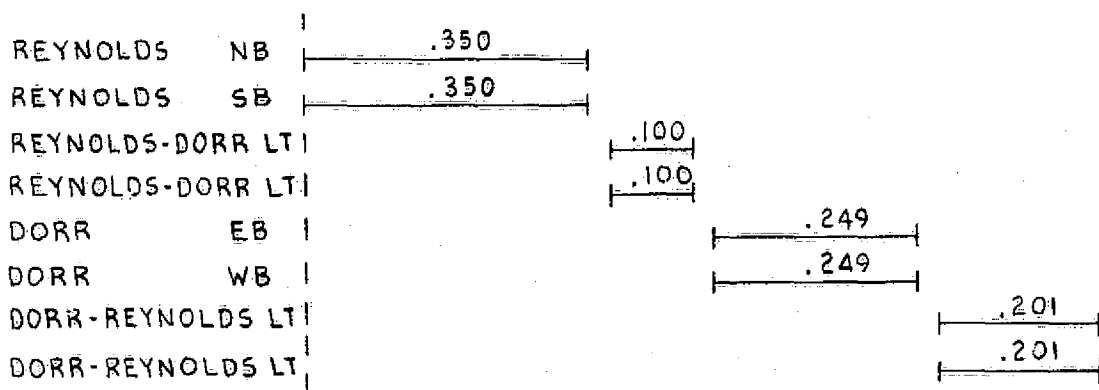
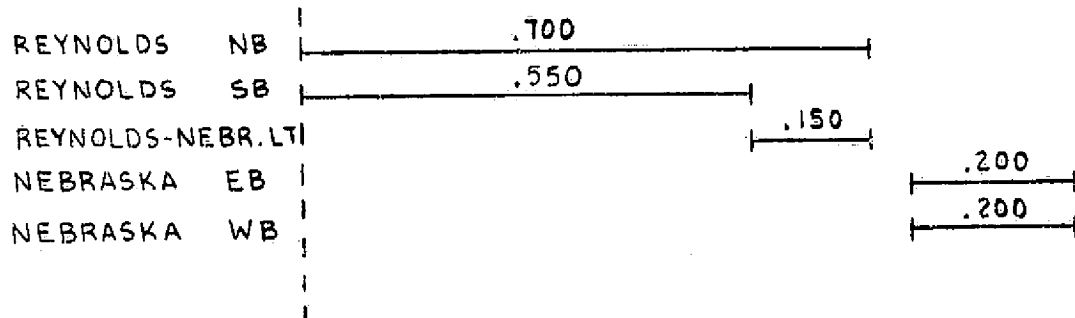
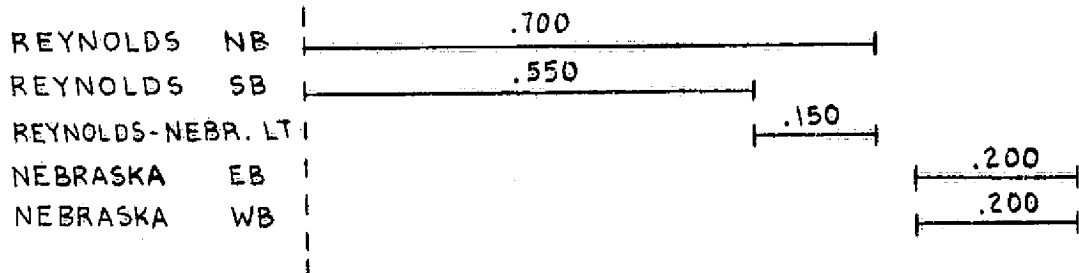


Figure 7-3(h). - Signal phasing - No. 512, Reynolds-Dorr.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

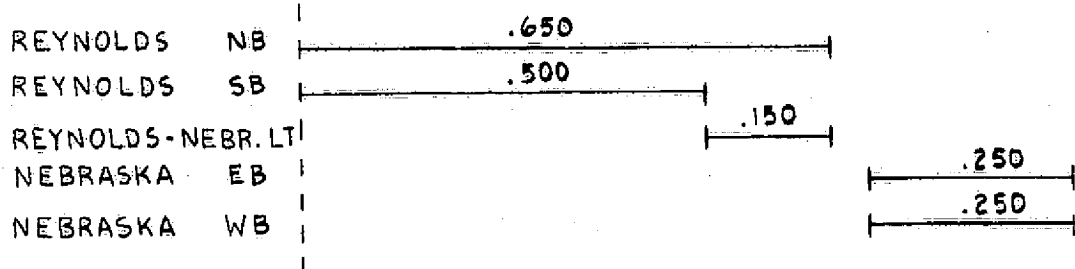
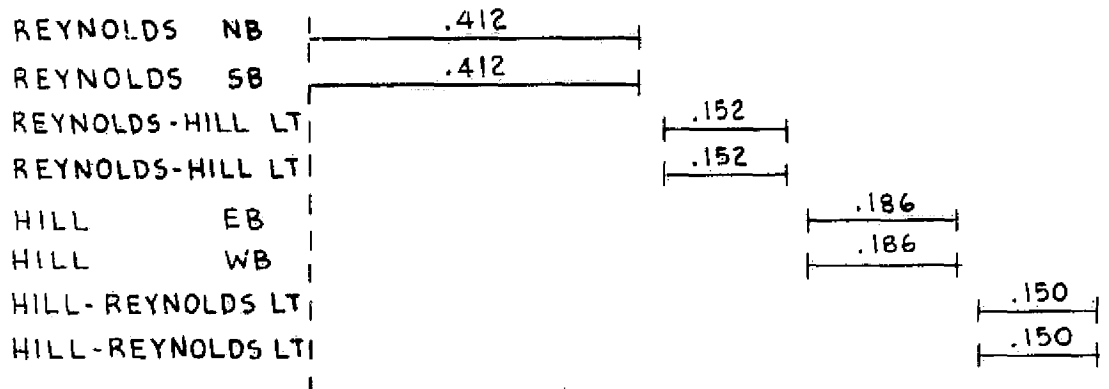


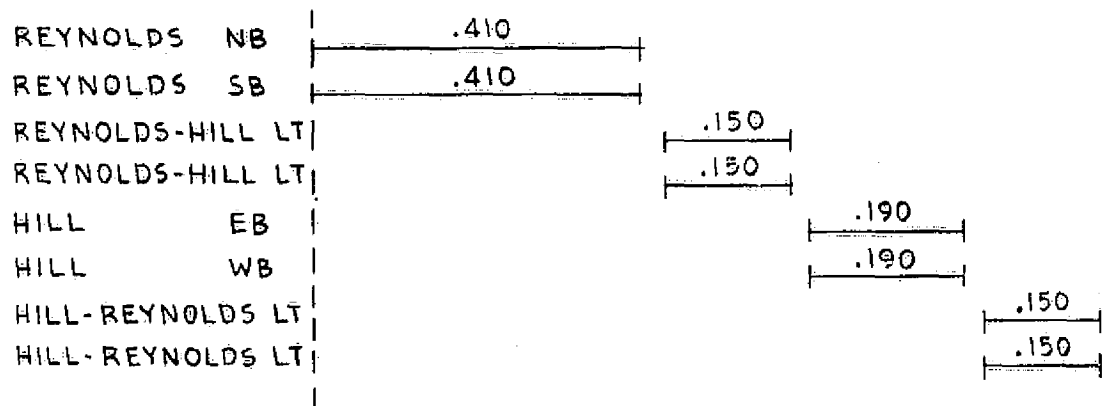
Figure 7-3(i). - Signal phasing - No. 587, Reynolds-Nebraska.

CYCLE TIME: 90 SEC.

TIME OF DAY: 7-9 a.m.



TIME OF DAY: 11-1 p.m.



TIME OF DAY: 3-6 p.m.

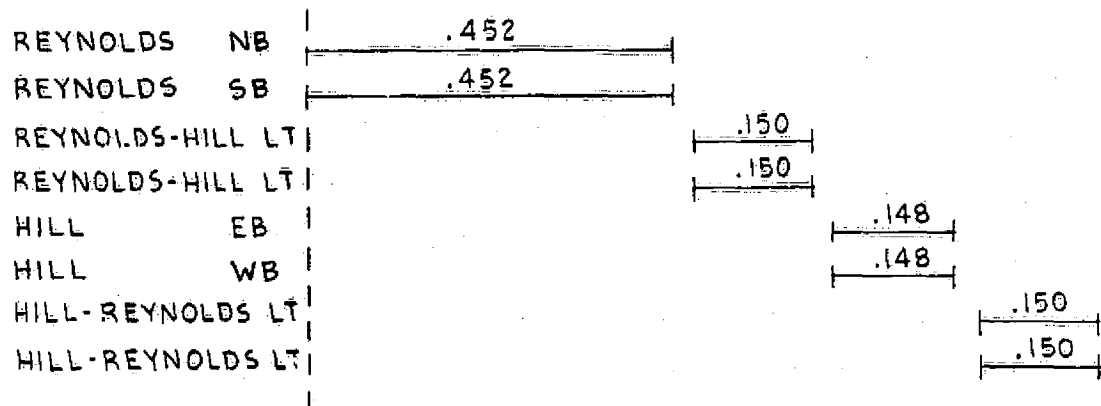


Figure 7-3(j). - Signal phasing - No. 499, Reynolds-Hill.

Reynolds-Bancroft to proceed. The same procedure was used for the Bancroft traffic. After a short green band, the Bancroft W-B traffic was stopped to allow the Bancroft-Reynolds LT traffic to proceed through the intersection.

A progression timing plan along major arteries in section I is presented in figures 7-4 to 7-4(b). Assuming a ninety second signal cycle, the green and red bands for the intersections can be designated. The diagram was established by displacing the green band of the next intersection by the required travel time for the platoons. In a progression system it is difficult to synchronize the traffic signals in both directions. Therefore, progression is applied to the direction with higher traffic flow. The timing plan merely illustrates an approach to displacing the start of a green band to ensure uninterrupted traffic flow. The timing plan is applicable to the proposed traffic algorithm. However, arriving platoons will be halted by the waiting vehicles.

The optimal traffic signal settings were used to compute the behavior of the vehicle queues at each intersection throughout the network. The results are presented in figures 7-5 to 7-7(h) for the three intervals. The results for the 7-9 a.m. interval are presented in figures 7-5 to 7-5(h). Since only the average behavior of the queues is of interest, these figures indicate the overall condition of the queues for several signal cycles. The actual incremental decrease of the queues during the green band is not shown in these plots. The two graphs compare the results obtained with the proposed traffic signal settings (solid lines) and the Toledo signal settings (dotted lines). The results for the proposed signal settings indicate that for the

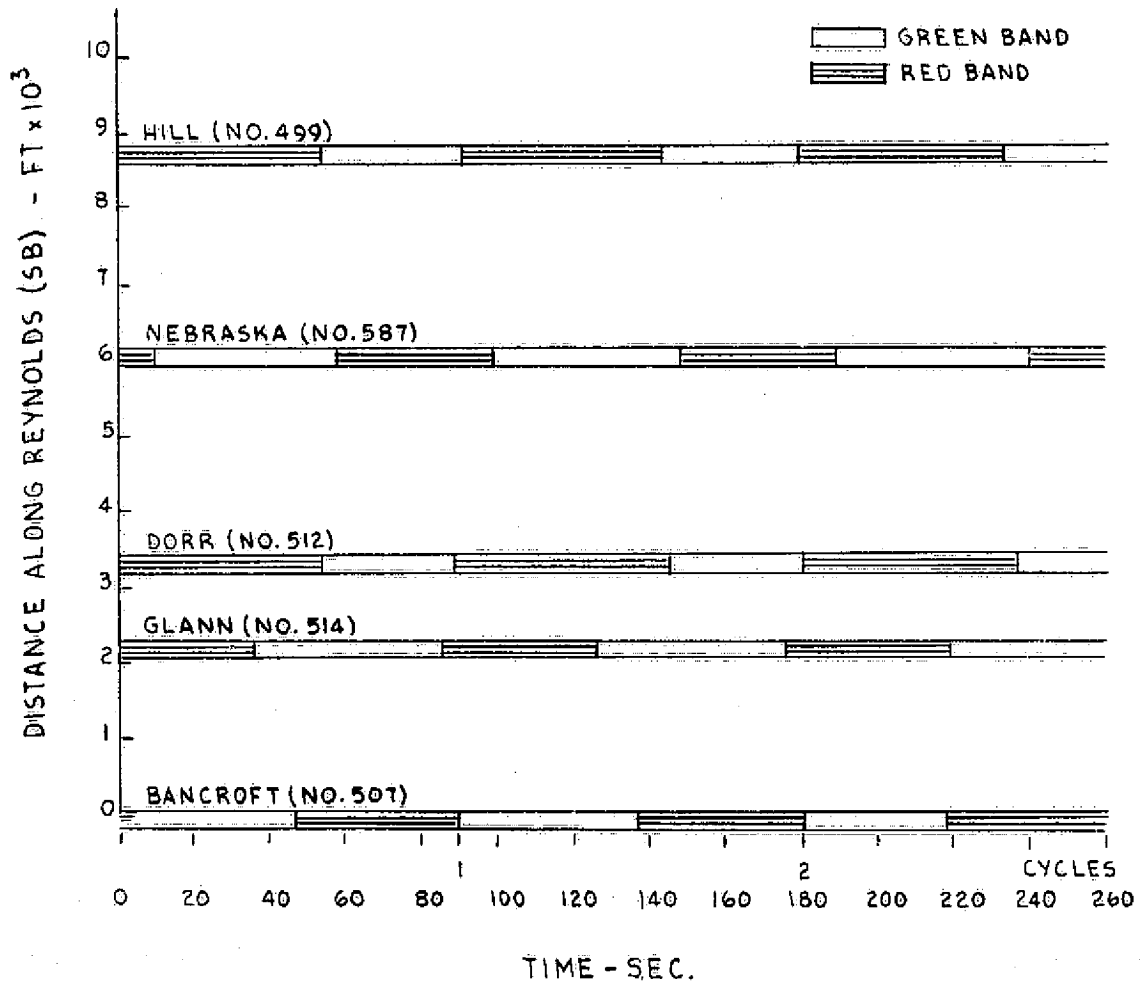


Figure 7-4. - Timing for traffic signals along Reynolds Rd., Section I,  
direction: southbound, time of day: 7-9 a.m.



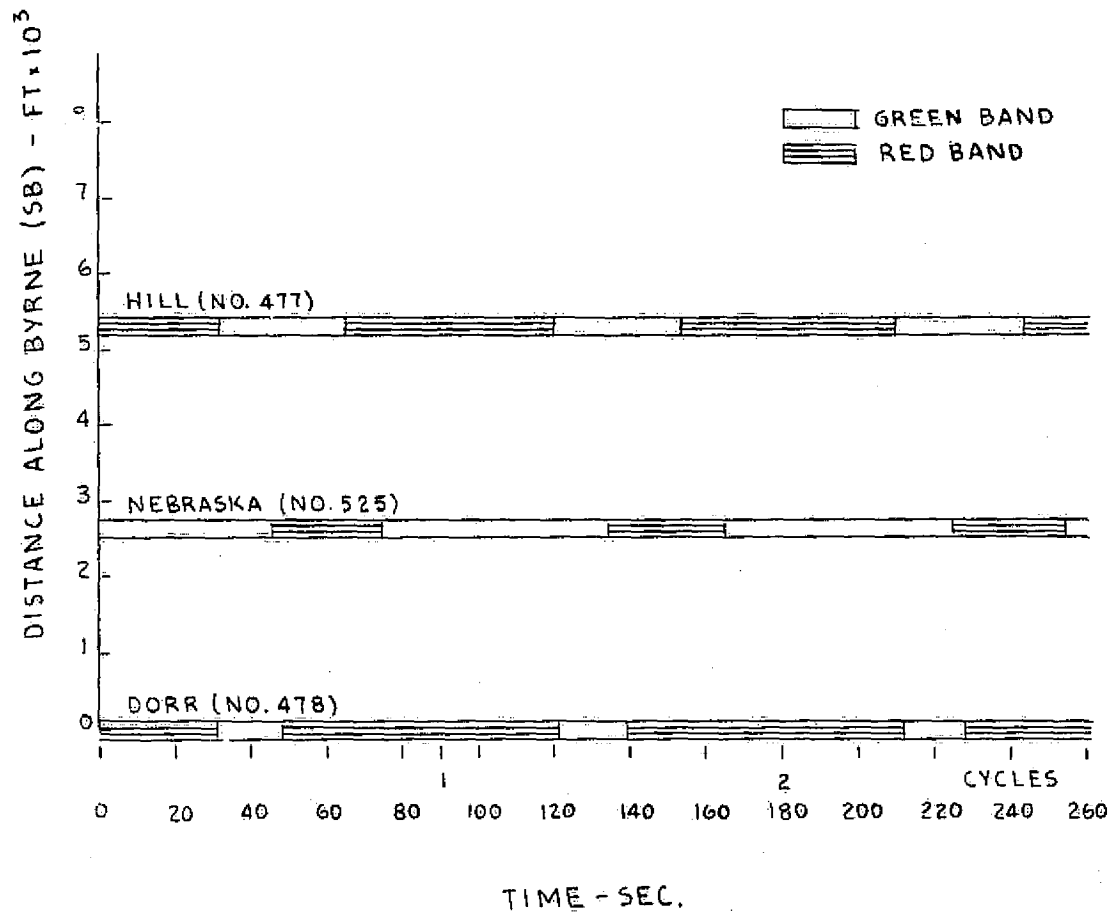


Figure 7-4(a). - Timing for traffic signals along Byrne Rd., Section I, direction: southbound, time of day: 7-9 a.m.

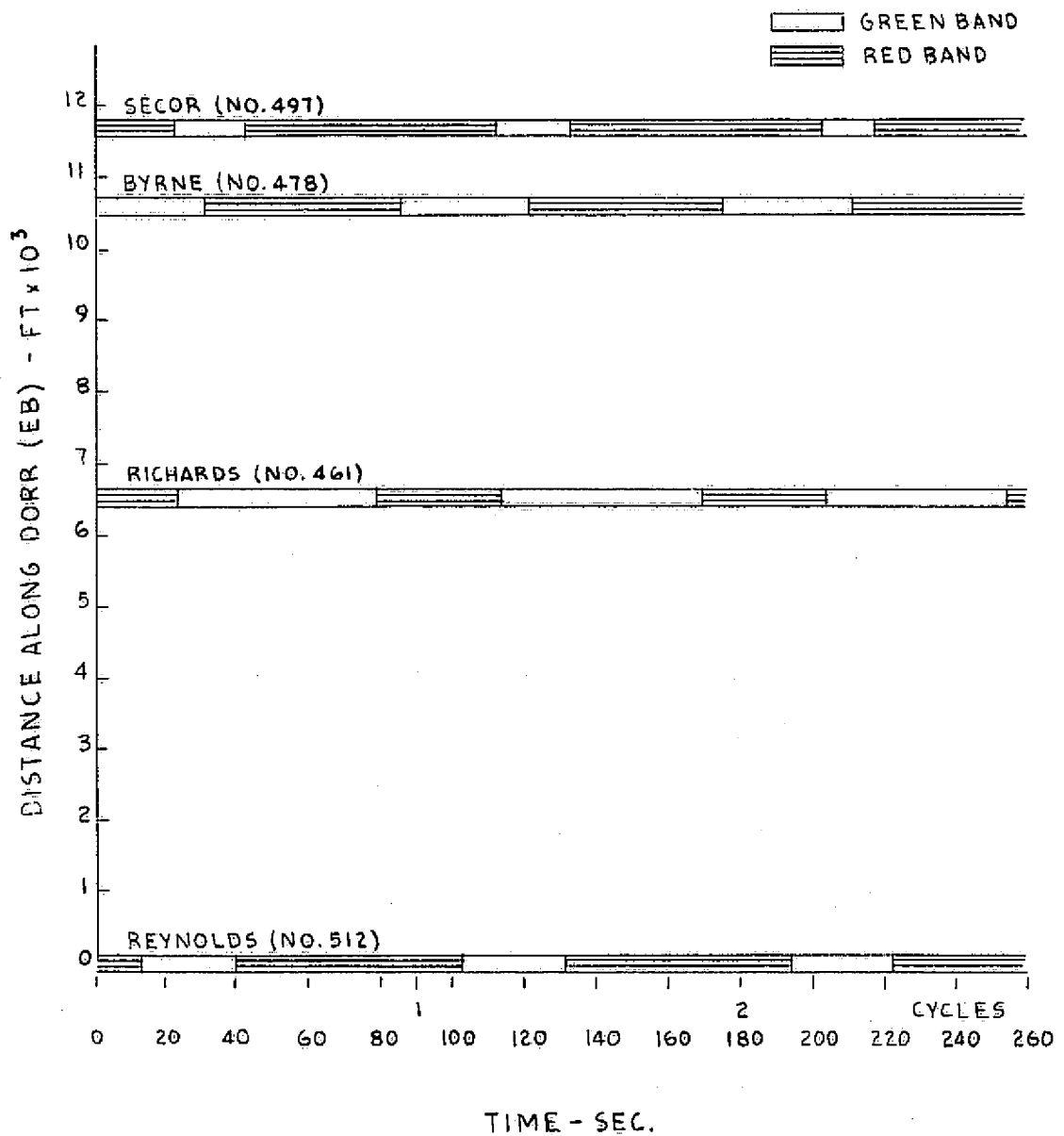


Figure 7-4(b). - Timing for traffic signals along Dorr St., Section I, direction: eastbound, time of day: 7-9 a.m.

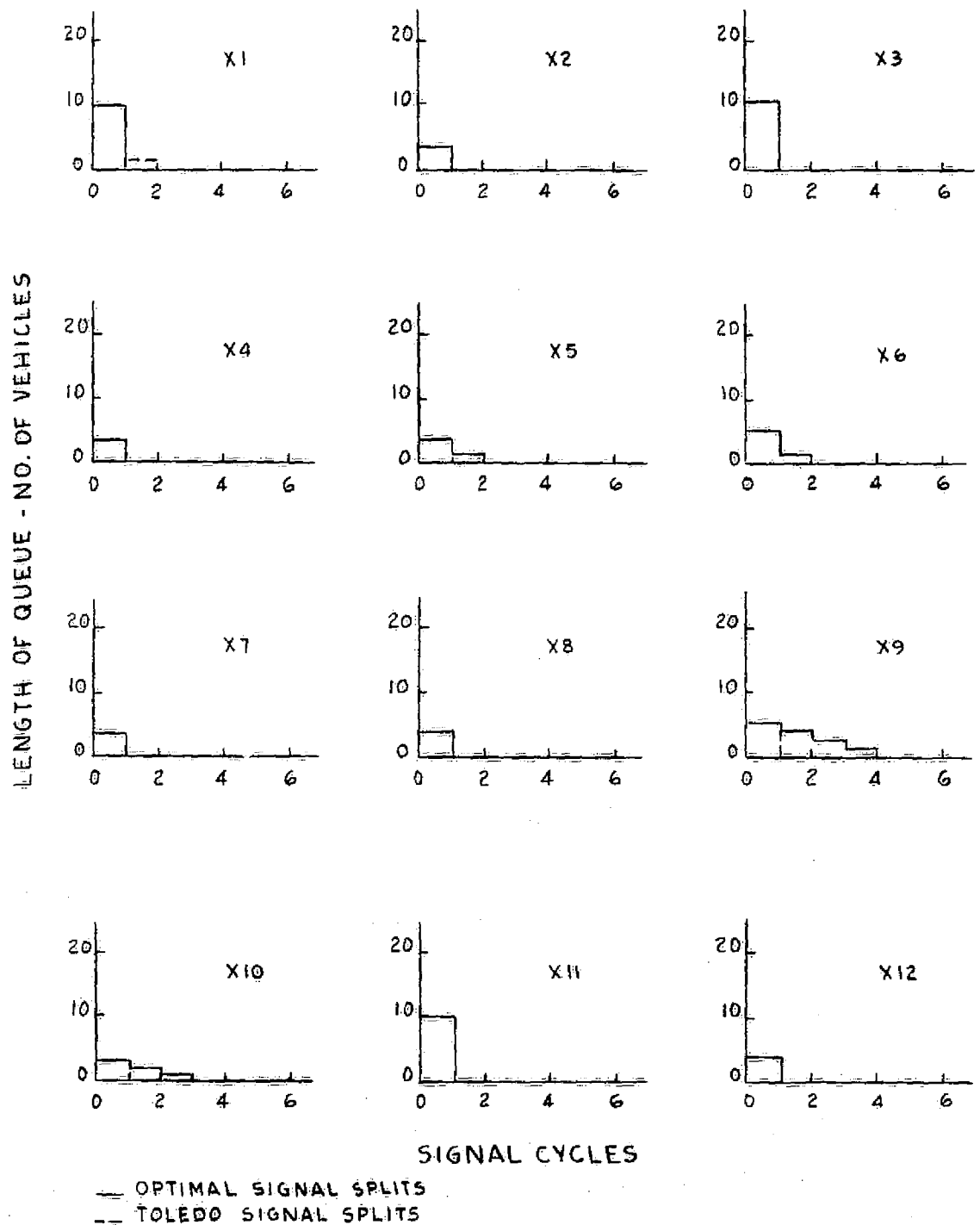


Figure 7-5. - Dissipation of vehicle queues, section I, 7-9 a.m.

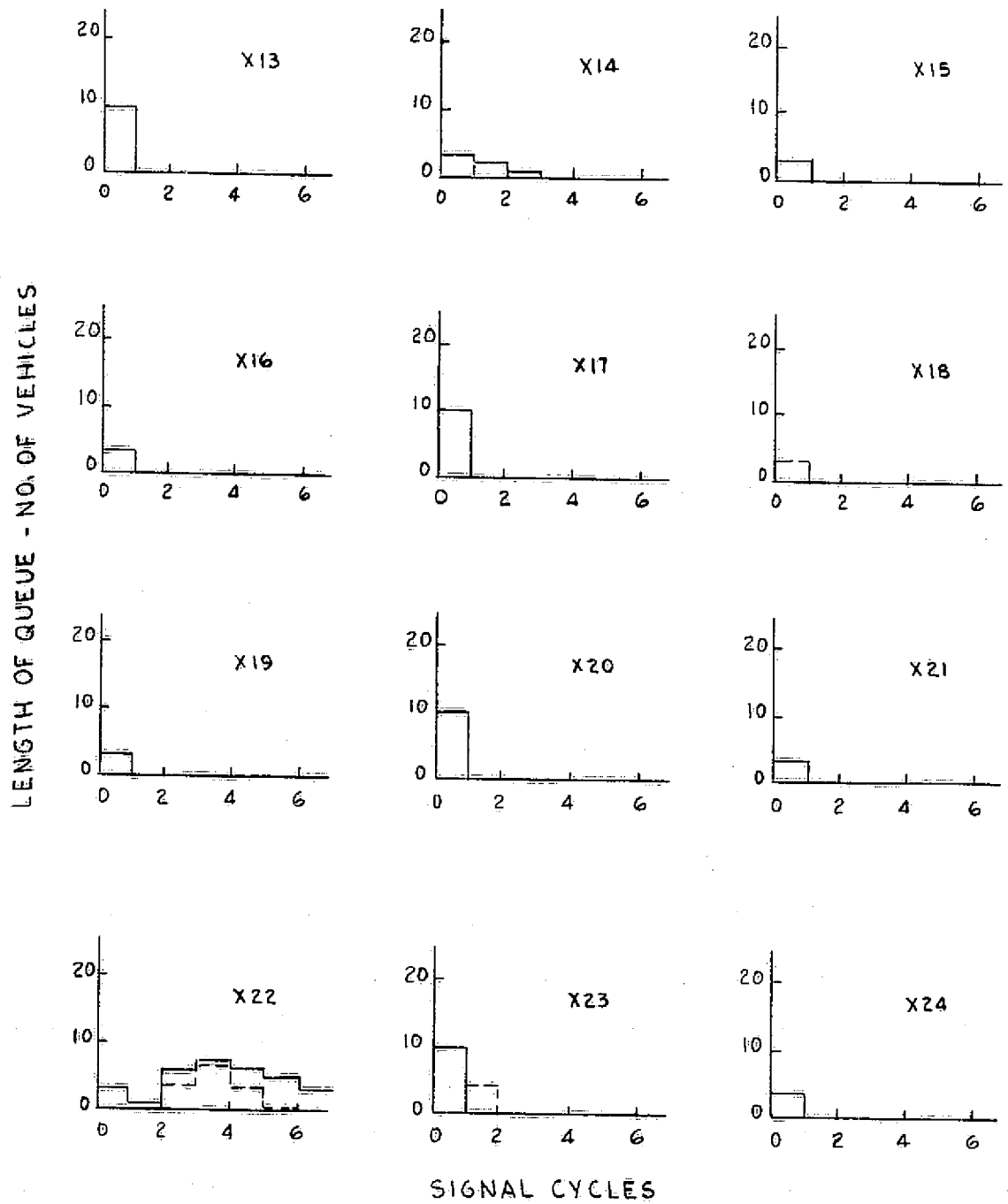


Figure 7-5(a). - Continued.

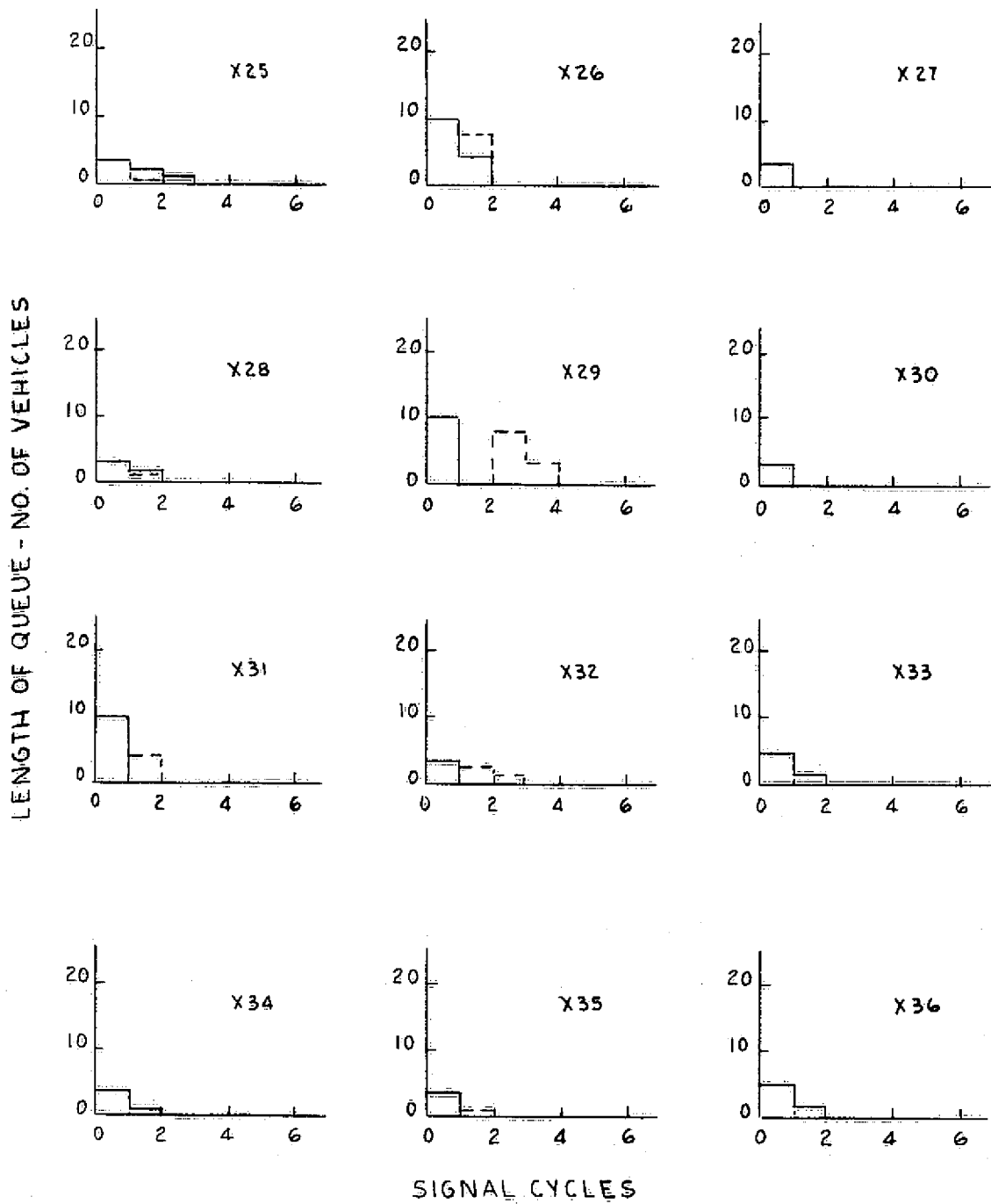


Figure 7-5(b). - Continued.

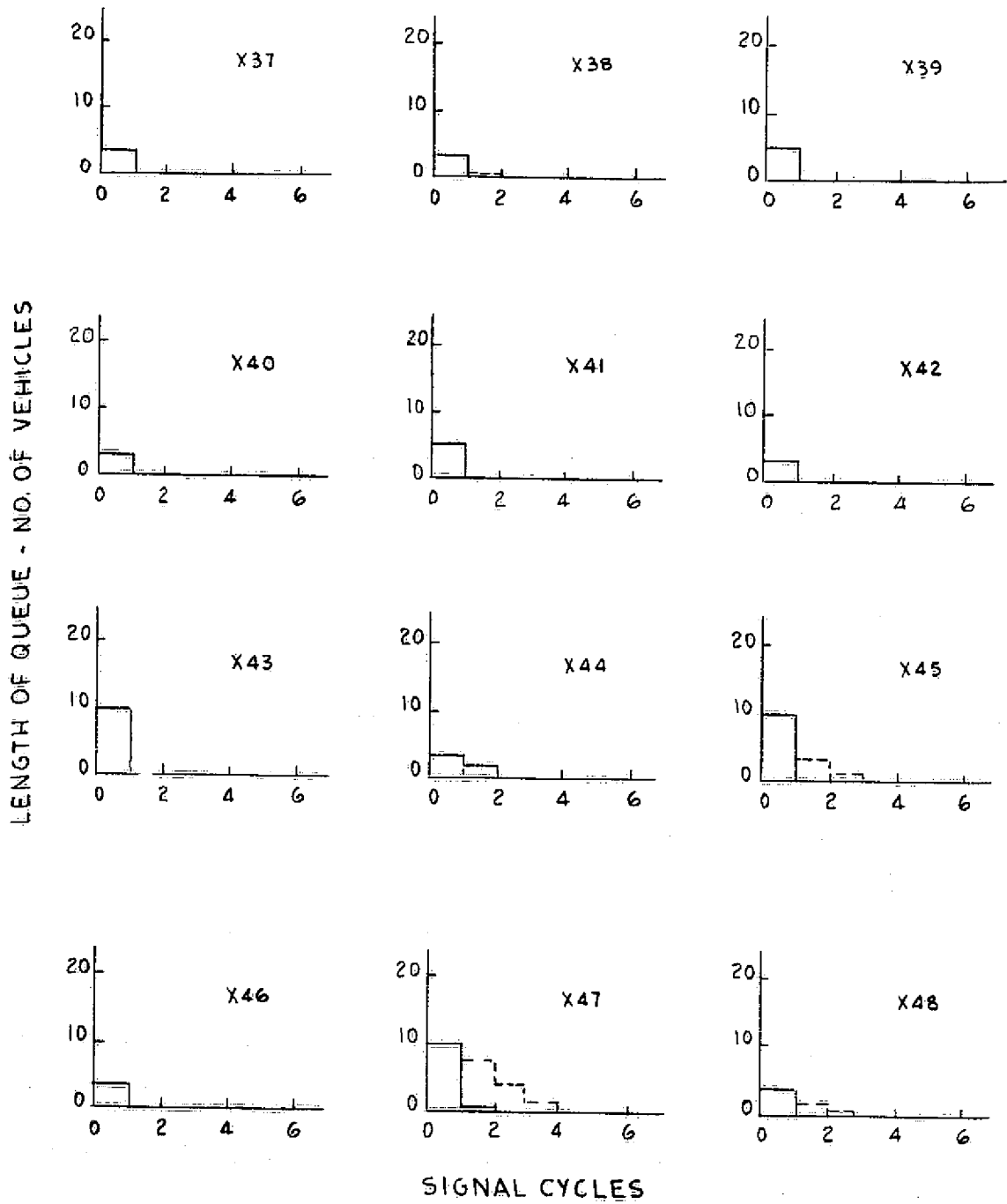
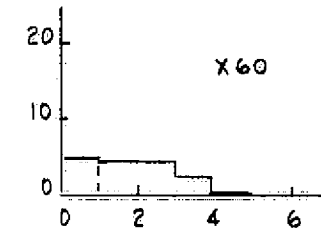
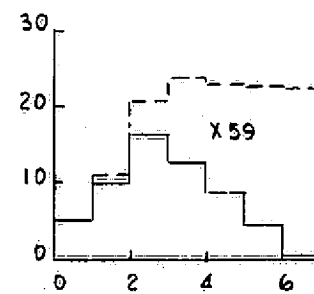
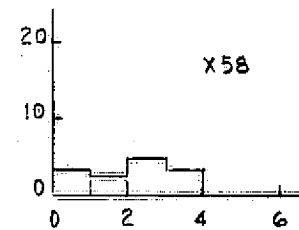
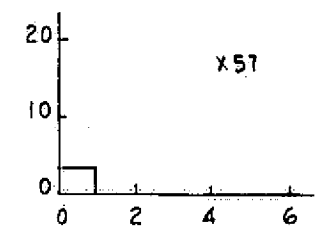
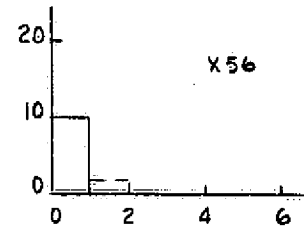
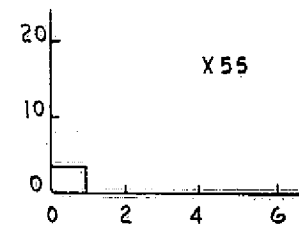
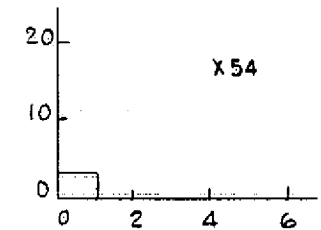
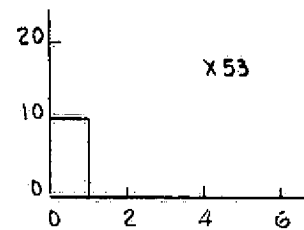
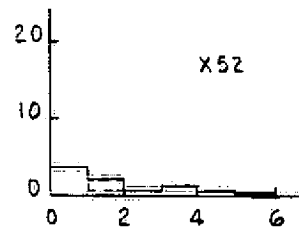
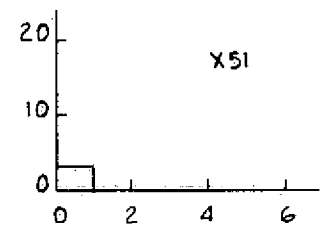
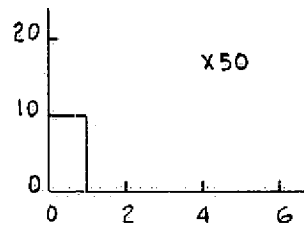
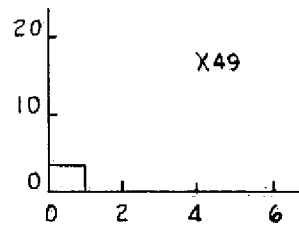


Figure 7-5(c). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 7-5(d). - Continued.

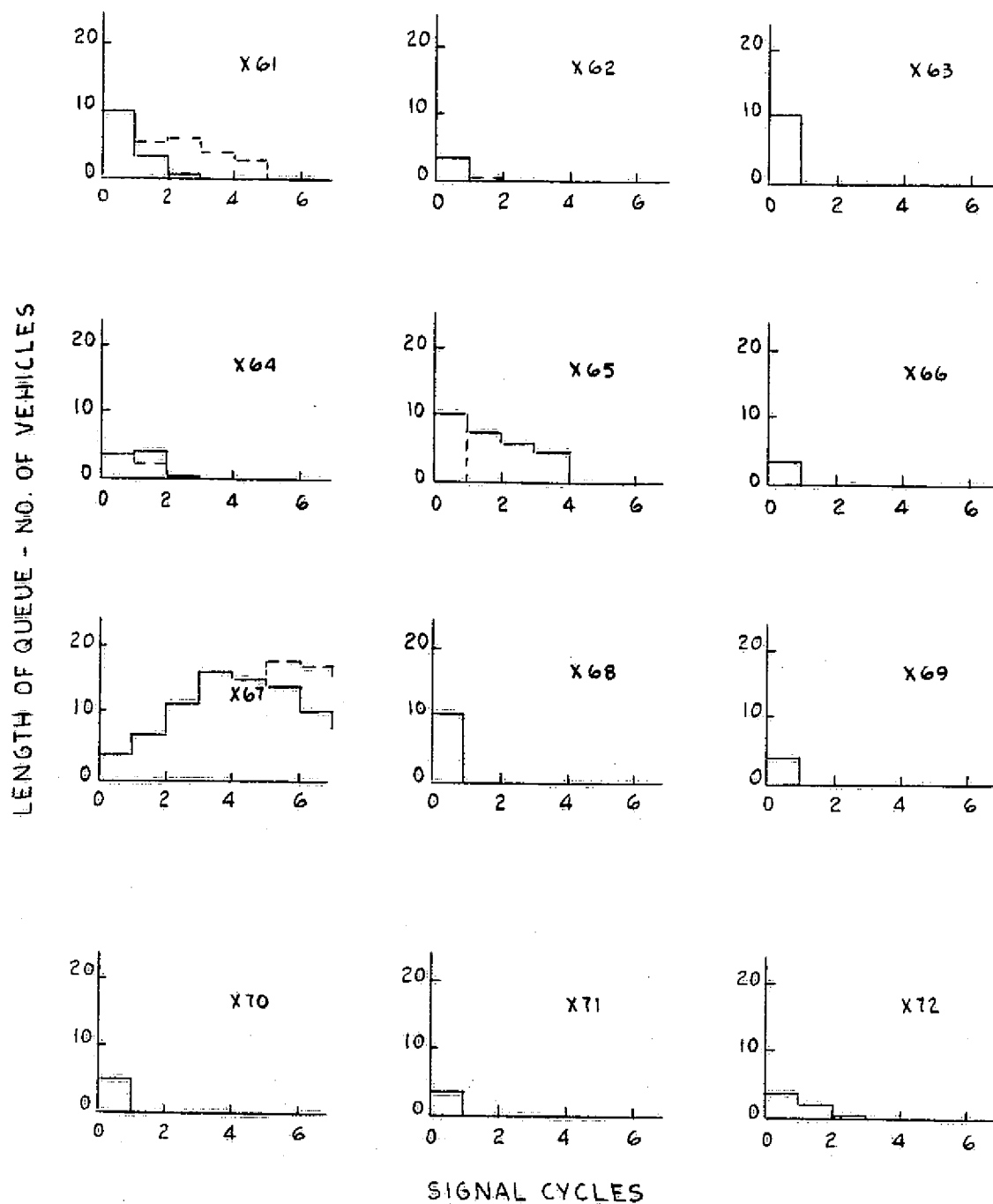


Figure 7-5(e). - Continued.



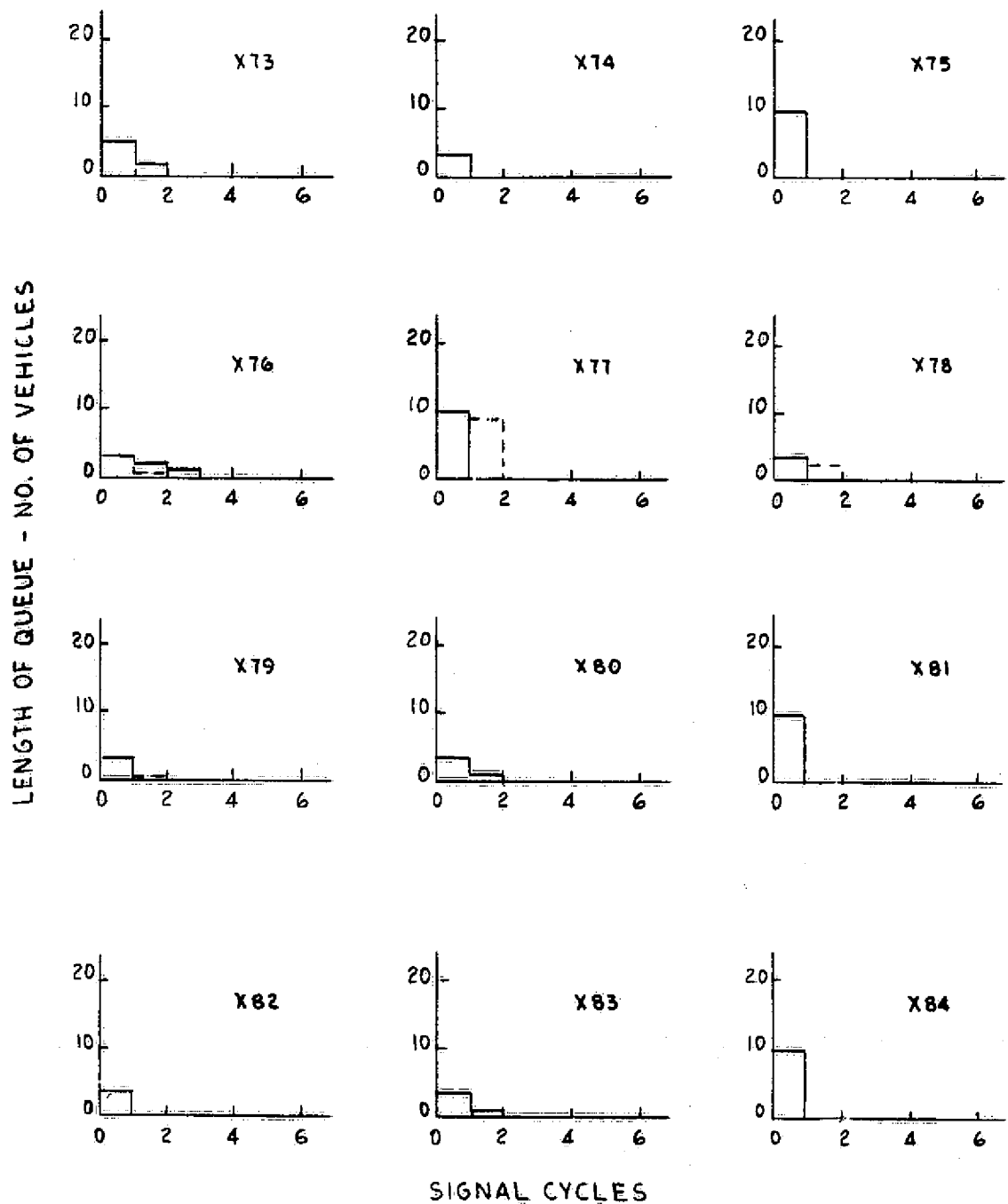


Figure 7-5(f). - Continued.

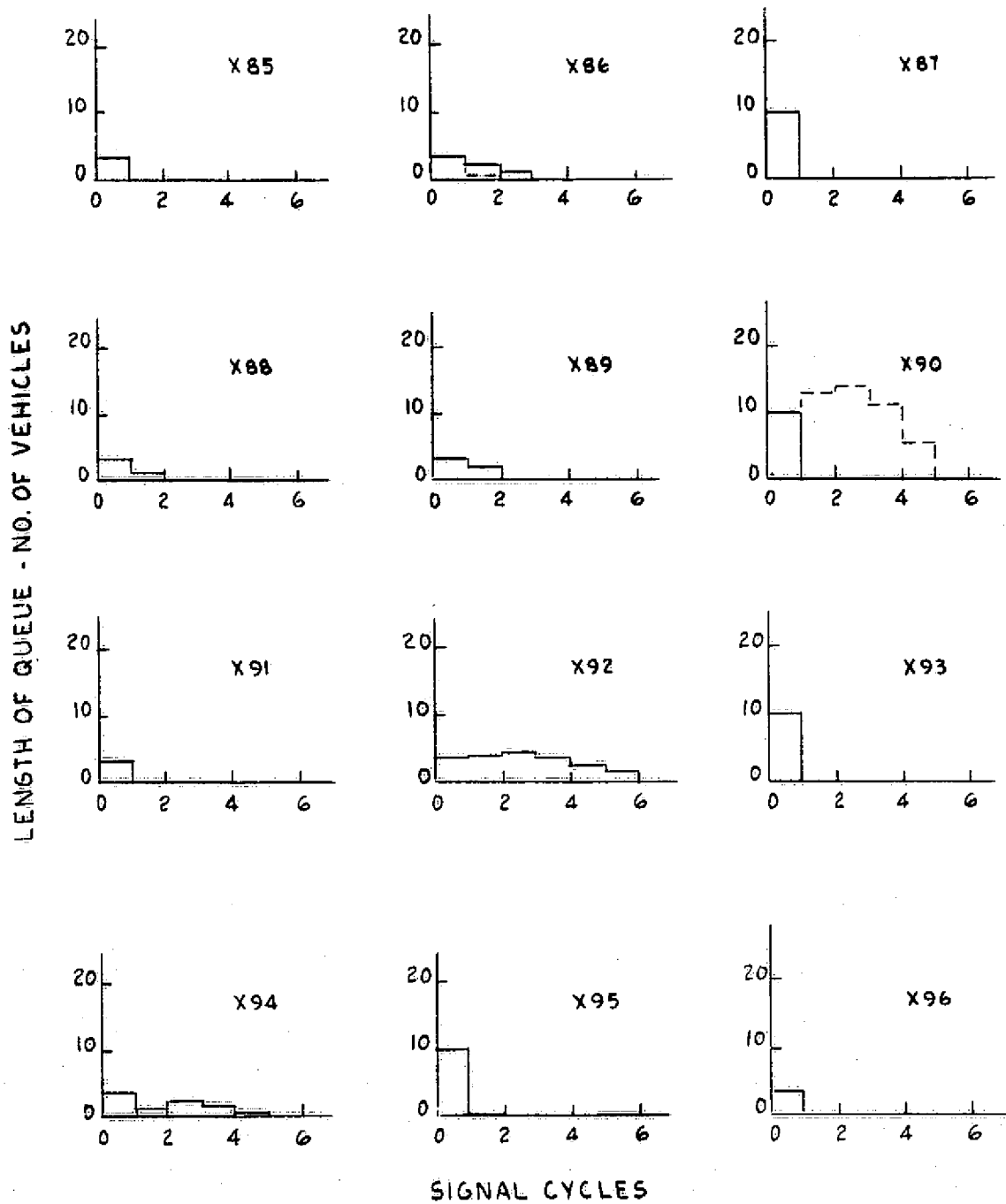


Figure 7-5(g). - Continued.

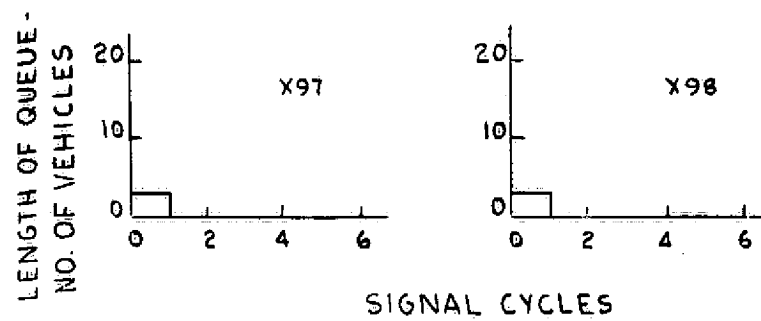


Figure 7-5(h). - Concluded.

assumed inflow and initial conditions, the vehicle queues are well-behaved and dissipate within a reasonable number of cycles. Several queues increase initially or whenever the platoons arrive at an intersection. However, the service rates are adequate to clear these queues. The critical queues are generally turning traffic such as Dorr-Reynolds LT (X22), Byrne-Dorr RT (X59), Dorr-Secor LT (X67), and Byrne-Hill LT (X92). The results presented for the two intersections (#478, #497) are different from those obtained in chapter VI. The reason is that the modeling of these intersections differs from the approach used previously. In order to move the traffic flow more efficiently, the two right turn queues (X59, X71) are allowed to turn with the two left turn queues (X64, X67). At the Byrne-Dorr intersection, the vehicles must turn either left or right, whereas at Secor-Dorr the majority of vehicles proceed to the right into Dorr. The main stream traffic in the Secor SB direction is very small.

In order to test the Toledo traffic signal settings, the model was slightly modified to comply with the Toledo traffic pattern. It can be noted from figures 7-5 to 7-5(h) that the signal settings effectively control the traffic flow within section I. Several queues are cleared rapidly, while others do not reduce as rapidly as for the proposed signal settings. The difficulties encountered for the Byrne-Dorr-Secor area are apparent with the Toledo signal settings. The critical queues (X59, X67) increase to high levels within several cycles. The Secor-Dorr right turn queue (X71) does not exhibit the large increase since traffic was allowed to proceed with the left turn traffic (X67) into Secor. This approach does not impose any difficulties for either W-B Dorr or Dorr-Secor LT traffic.

Similar data are presented in figures 7-6 to 7-6(h) for the 11-1 p.m. interval. The results also indicate that improved traffic control can be obtained with the proposed control settings. For the given traffic flow, all queues are eliminated quickly and no traffic build-up should be experienced. Several queues dissipate rapidly, but begin to increase after several cycles. Again, this condition results from the delay time of the discharged vehicles from previous intersections. The critical queues (X59, X67) increase, but should be cleared after about nine cycles.

The results for the proposed signal settings are compared with the Toledo control settings. With the exception of the Byrne-Dorr RT (X59) and Dorr-Secor LT (X67) all traffic queues are well behaved. These critical queues increase to saturation levels. The approach, demonstrated in chapter VI, by increasing the weighting of these critical queues will solve this difficulty. State weighting was not included in the present analysis since the problem was not encountered for the proposed control settings.

The traffic control analysis was repeated for the 3-6 p.m. interval. The results are presented in figures 7-7 to 7-7(h) and show that the vehicle queues are dissipated within several signal cycles. During the specified time interval, the traffic flow is slightly higher than for the preceding cases, thereby causing some queues to dissipate more slowly. Some queues such as Reynolds-Dorr LT (X28), Hill-Reynolds LT (X52), Dorr E-B (X61, X65), Hill W-B (X84), and Byrne S-B (X90) increase to slightly higher levels. However, all queues are cleared within nine cycles. The critical queues within the Byrne-Dorr-Secor area display similar properties as for the preceding cases. Although

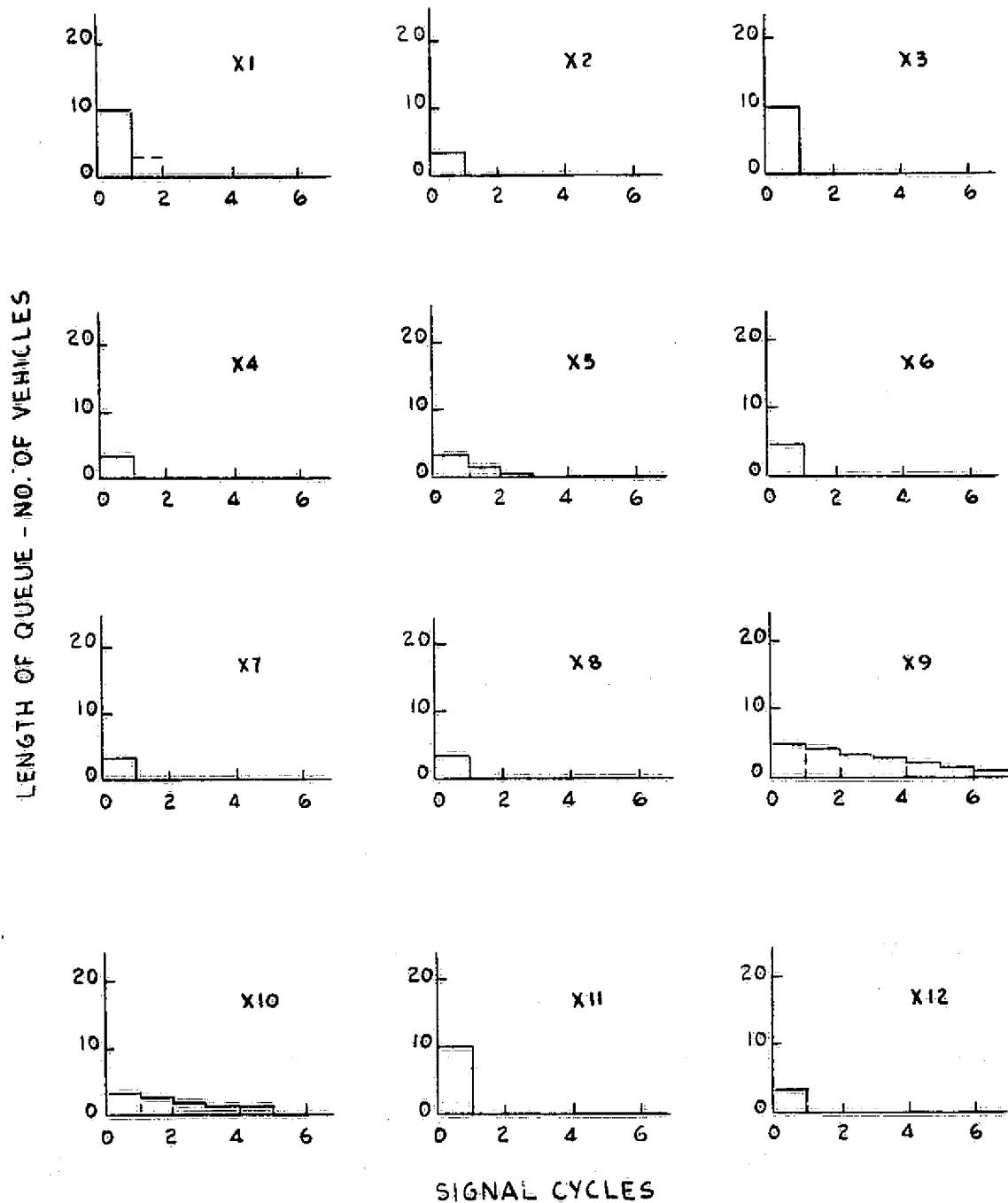


Figure 7-6. - Dissipation of vehicle queues, Section I, 11-1 p.m.

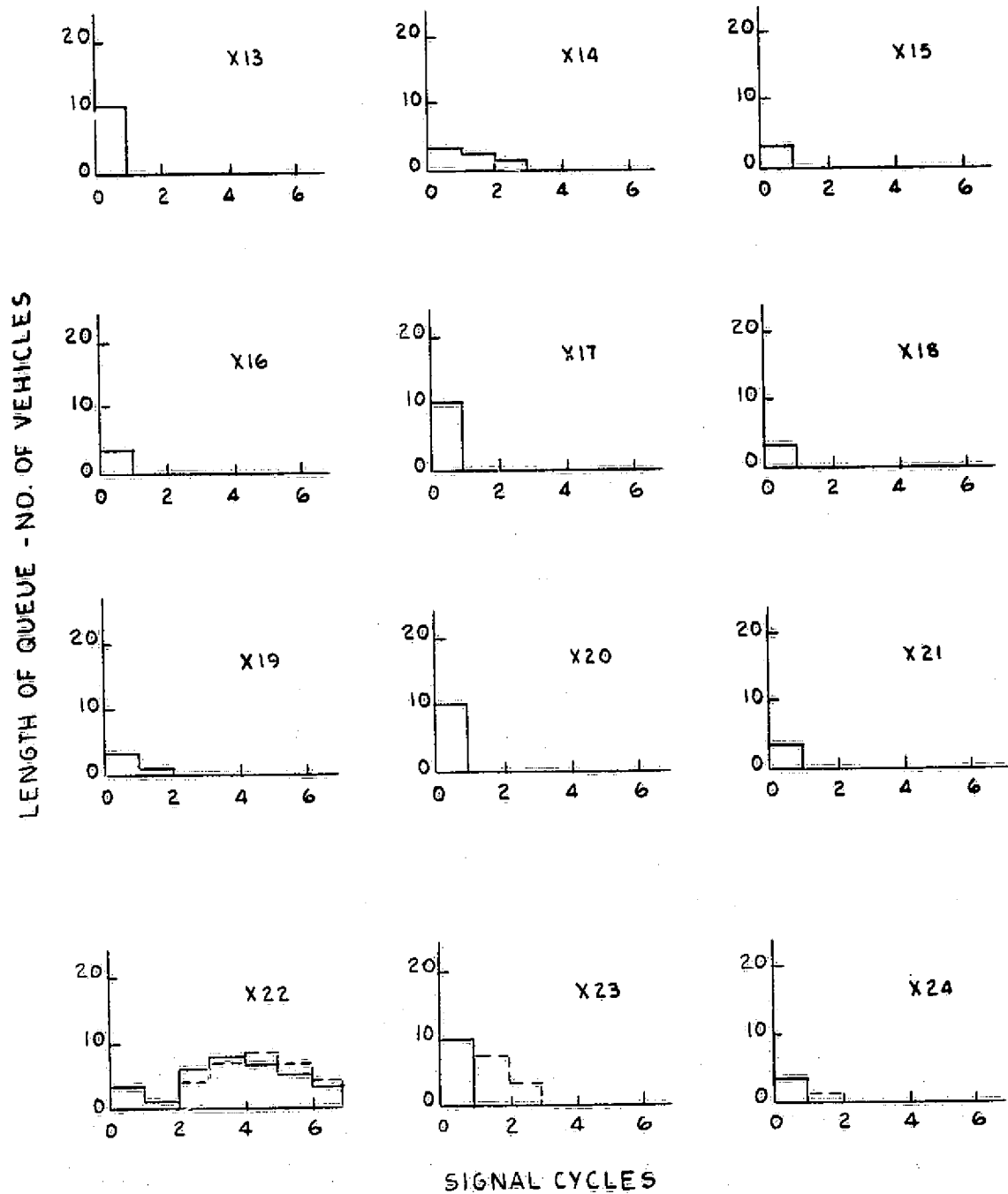


Figure 7-6(a). - Continued.

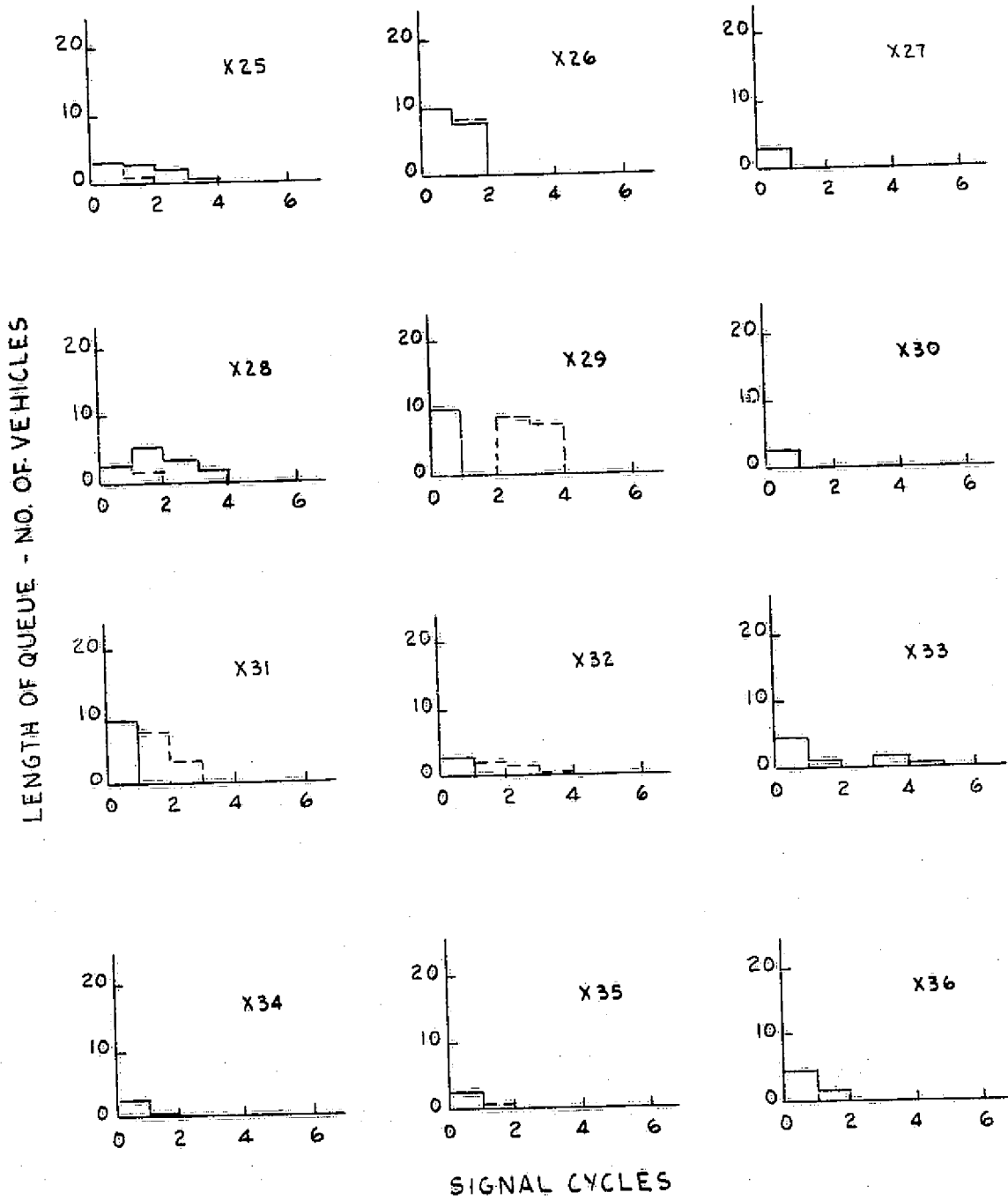


Figure 7-6(b). - Continued.



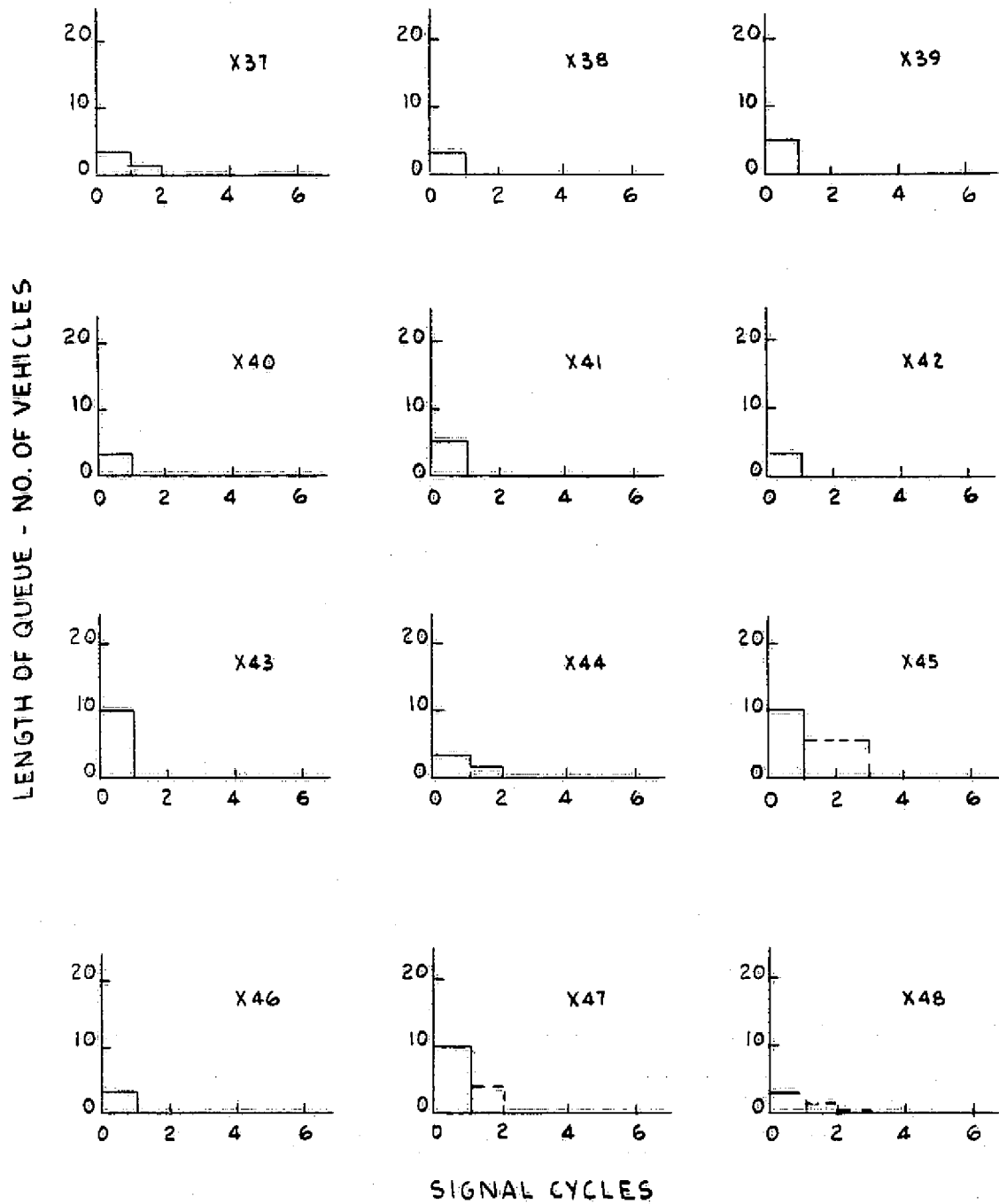


Figure 7-6(c). - Continued.

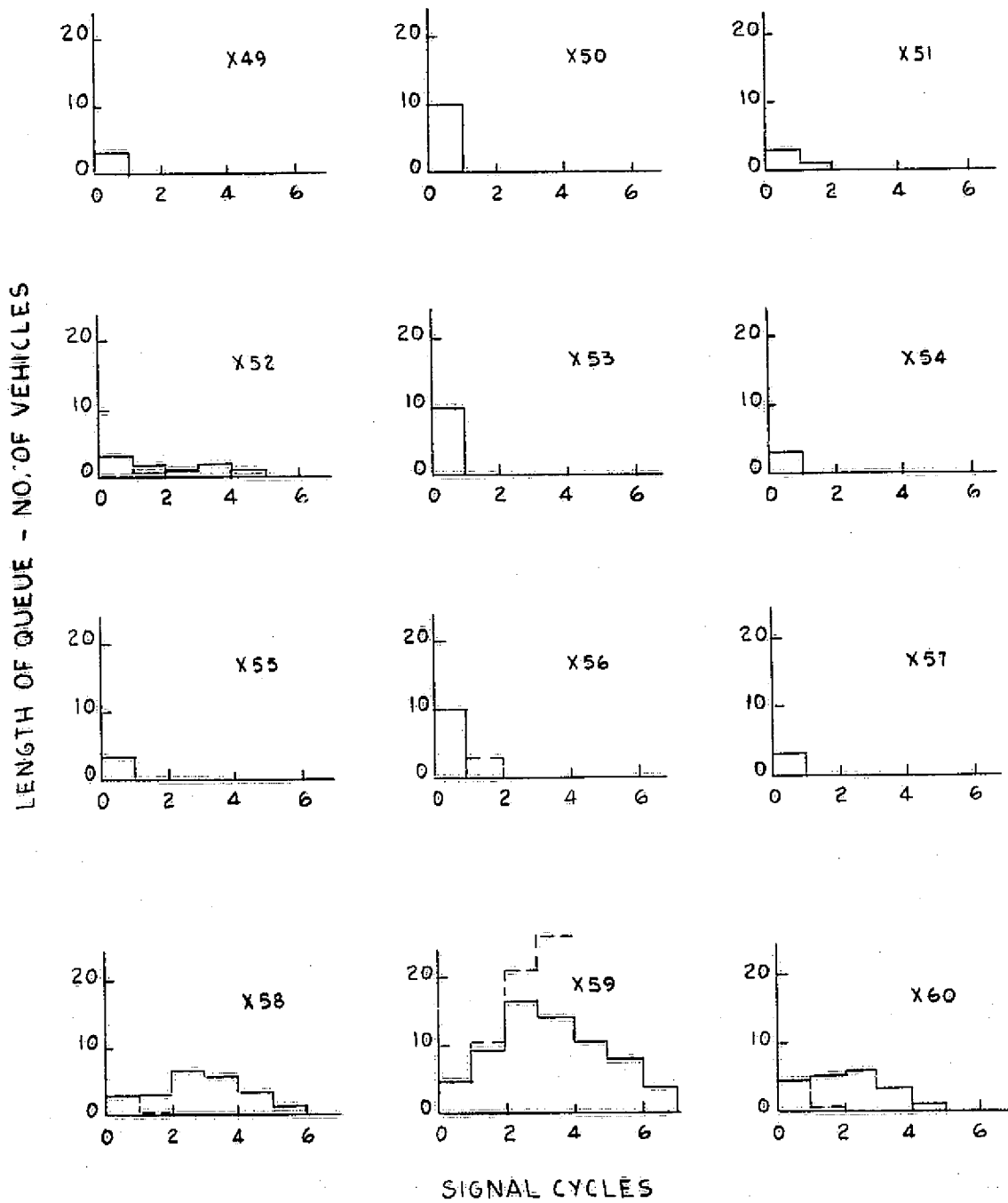


Figure 7-6(d). - Continued.

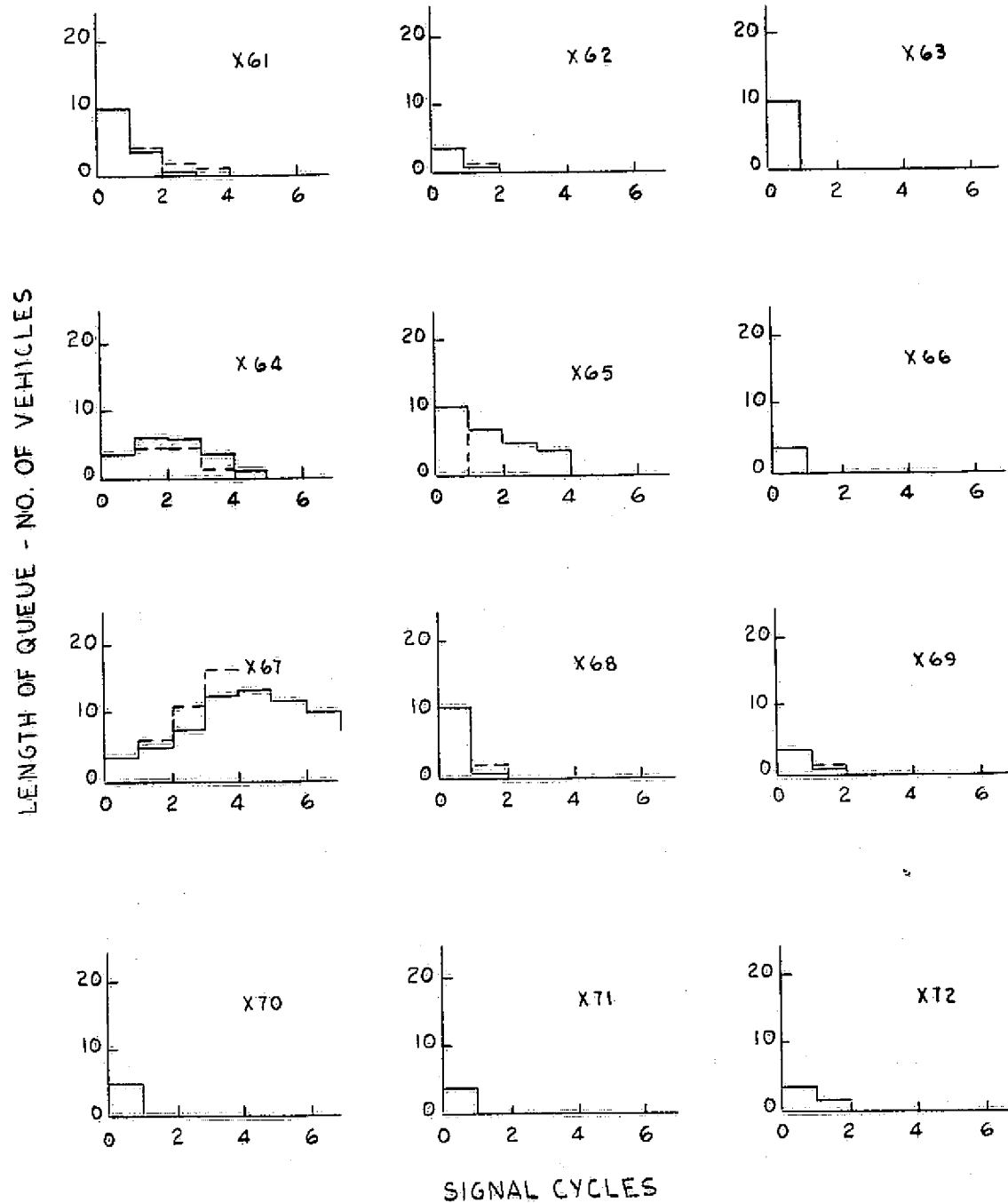
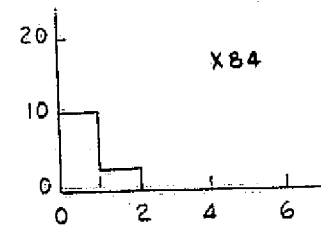
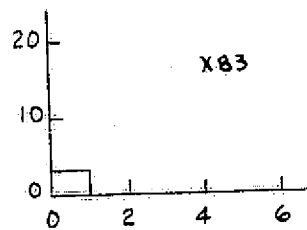
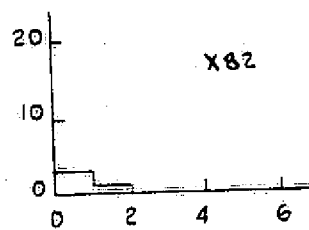
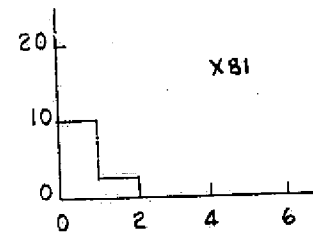
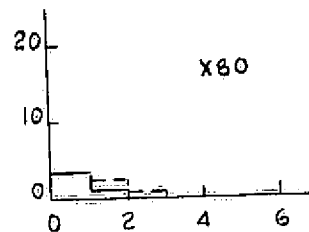
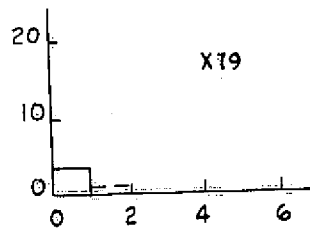
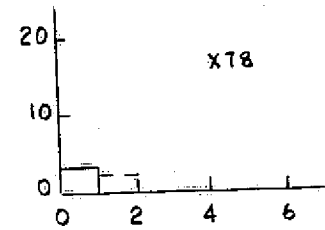
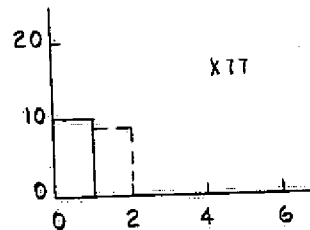
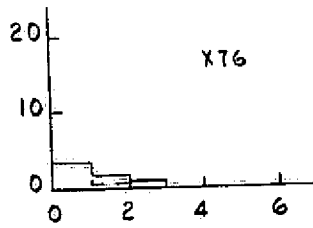
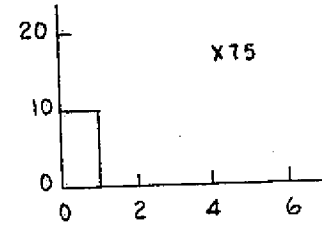
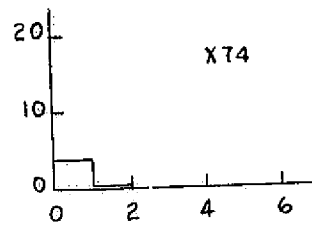
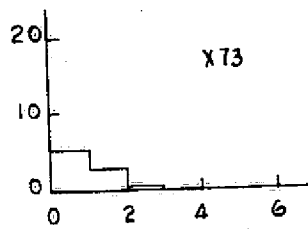


Figure 7-6(e). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 7-6(f). - Continued.

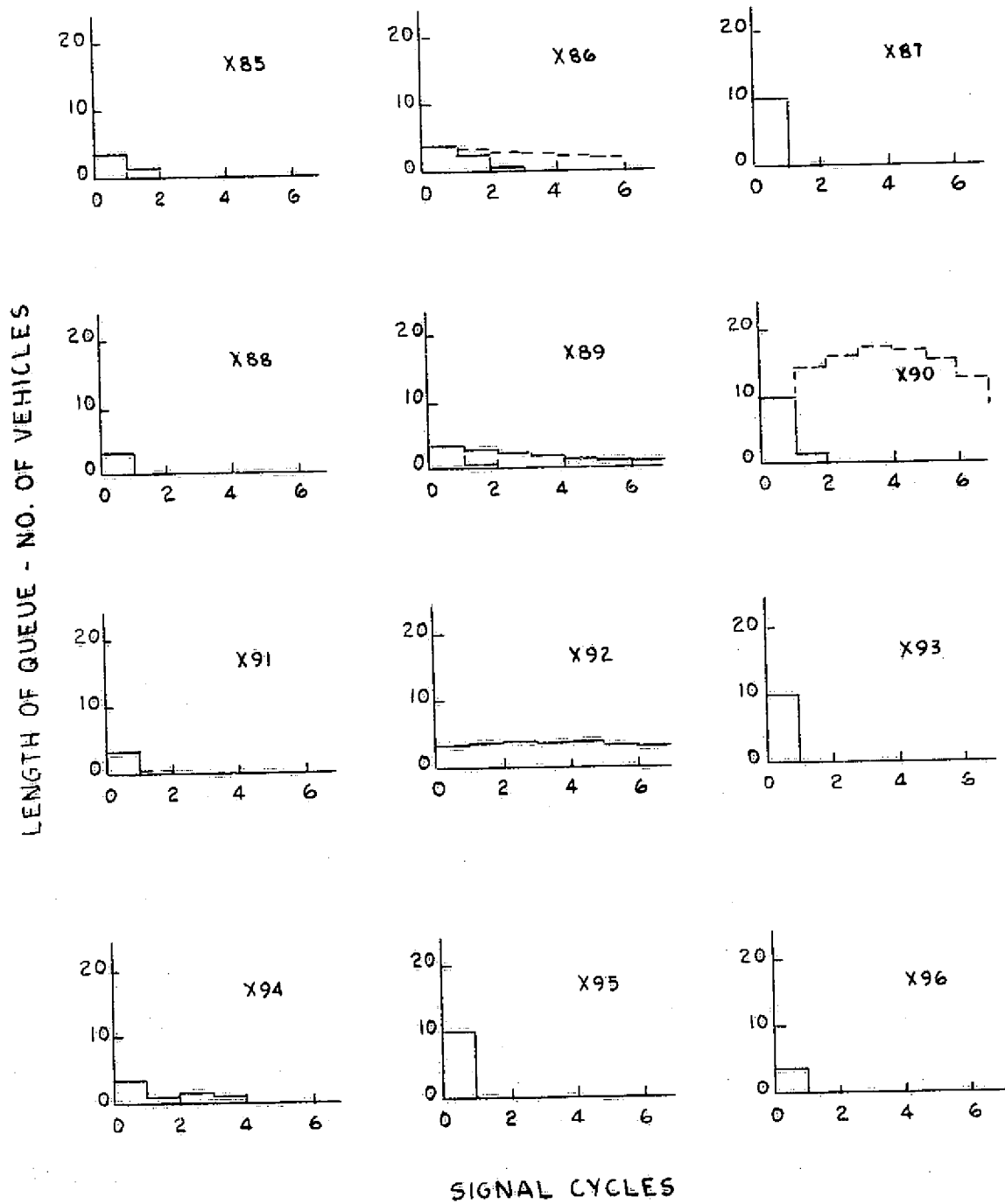


Figure 7-6(g). - Continued.

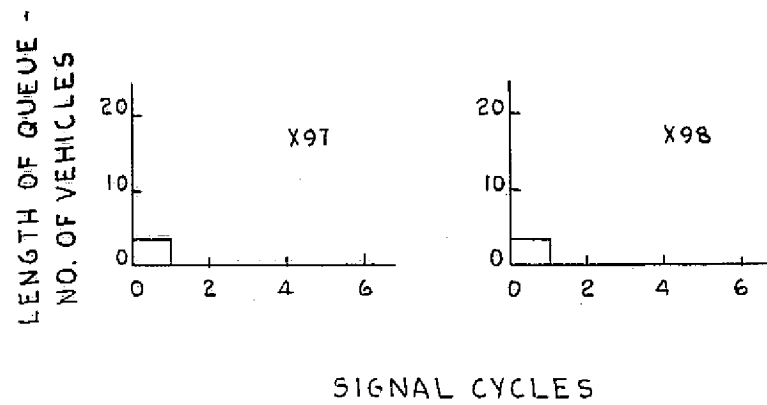


Figure 7-6(h). - Concluded.

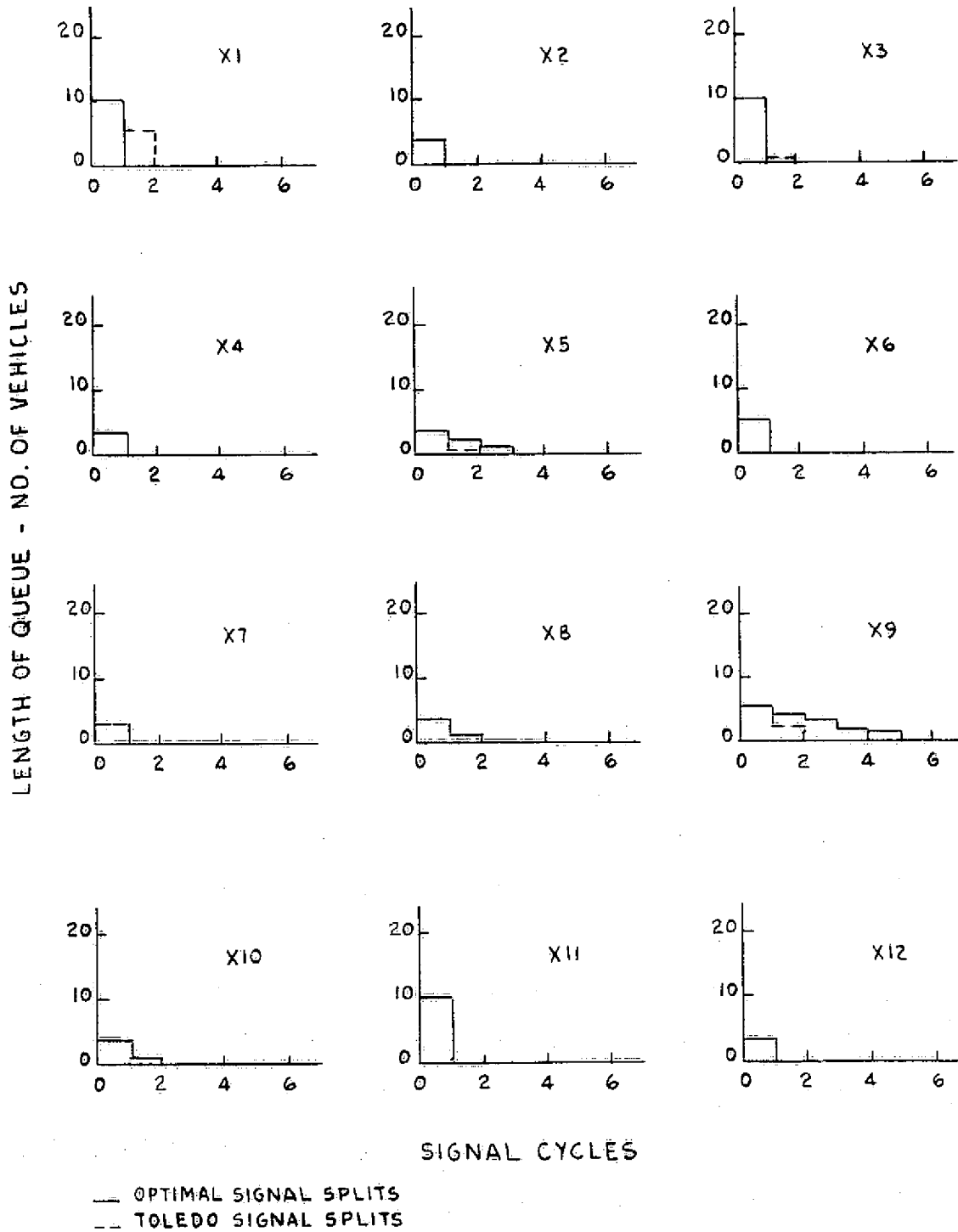


Figure 7-7. - Dissipation of vehicle queues, Section I, 3-6 p.m.

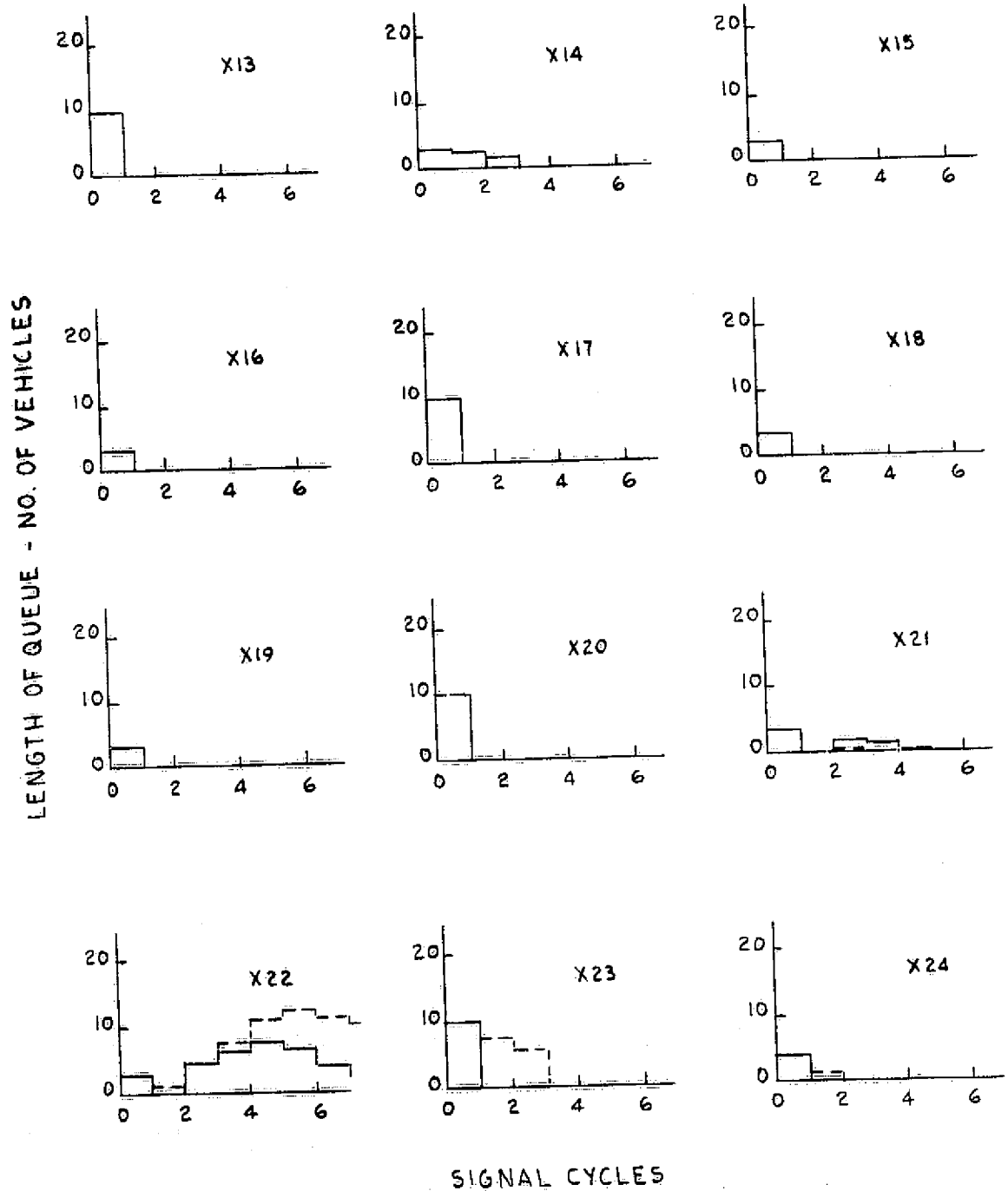


Figure 7-7(a). - Continued.



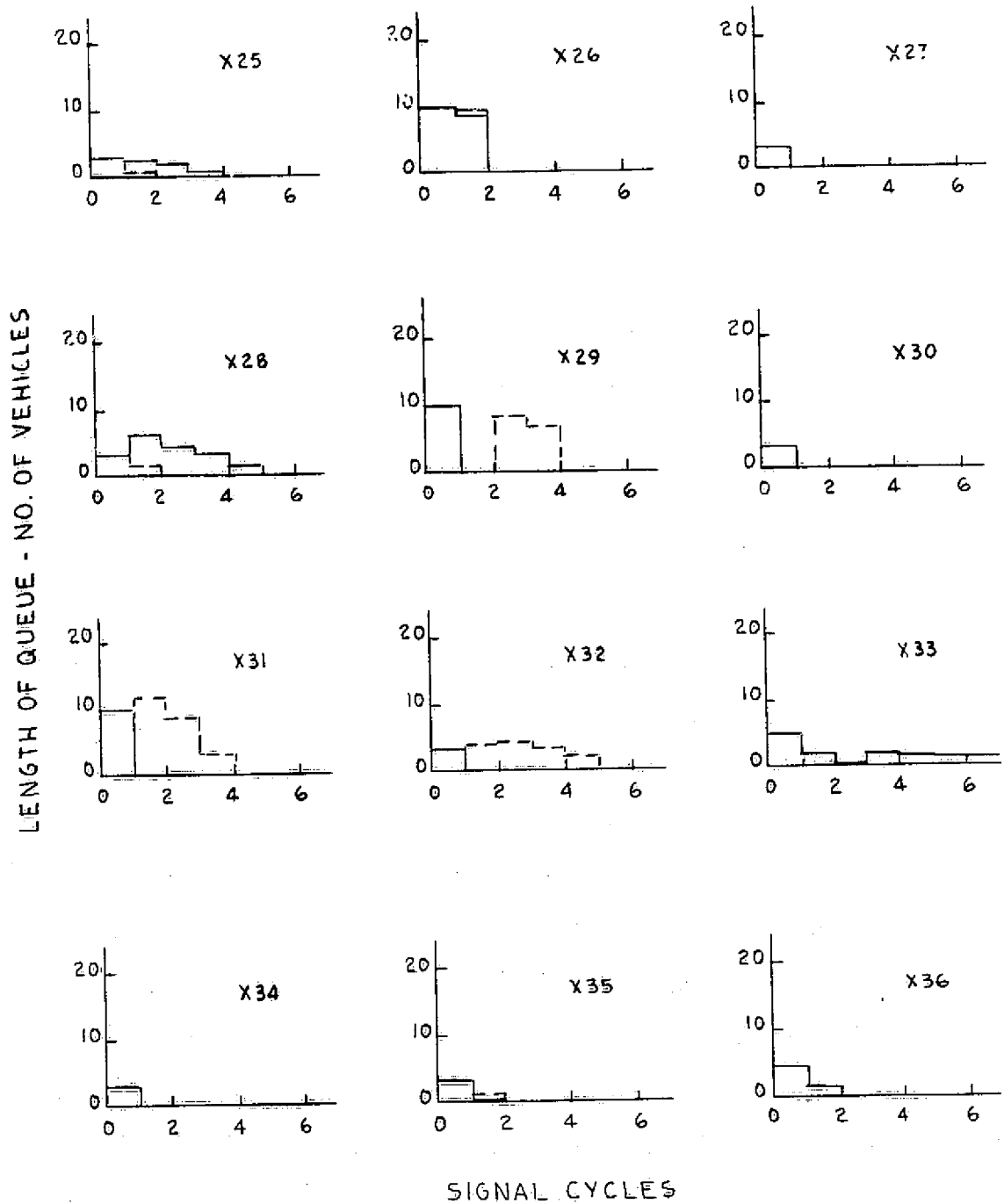
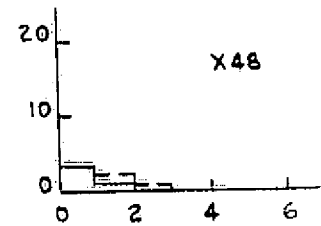
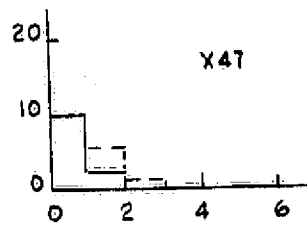
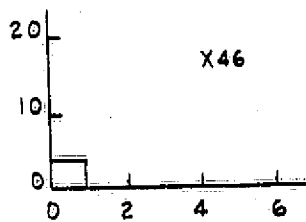
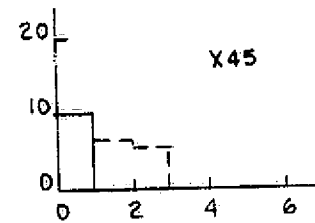
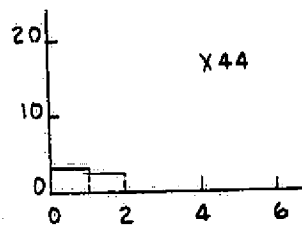
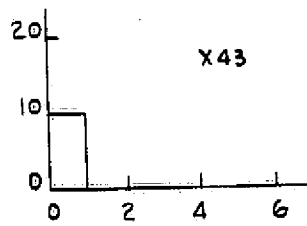
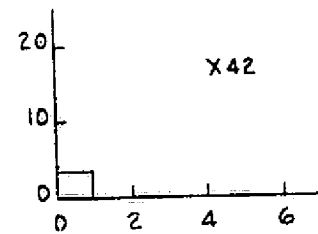
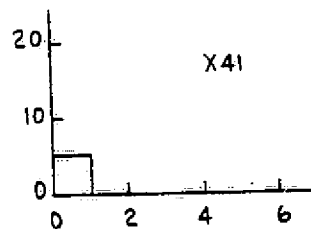
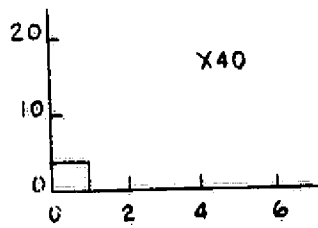
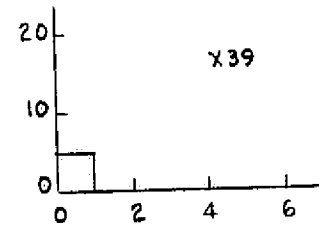
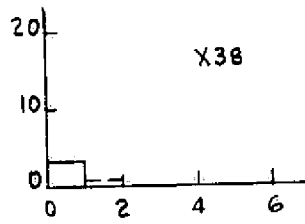
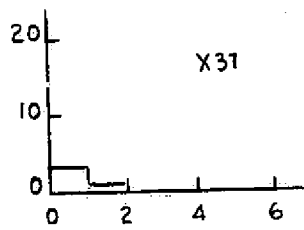


Figure 7-7(b). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 7-7(c). - Continued.

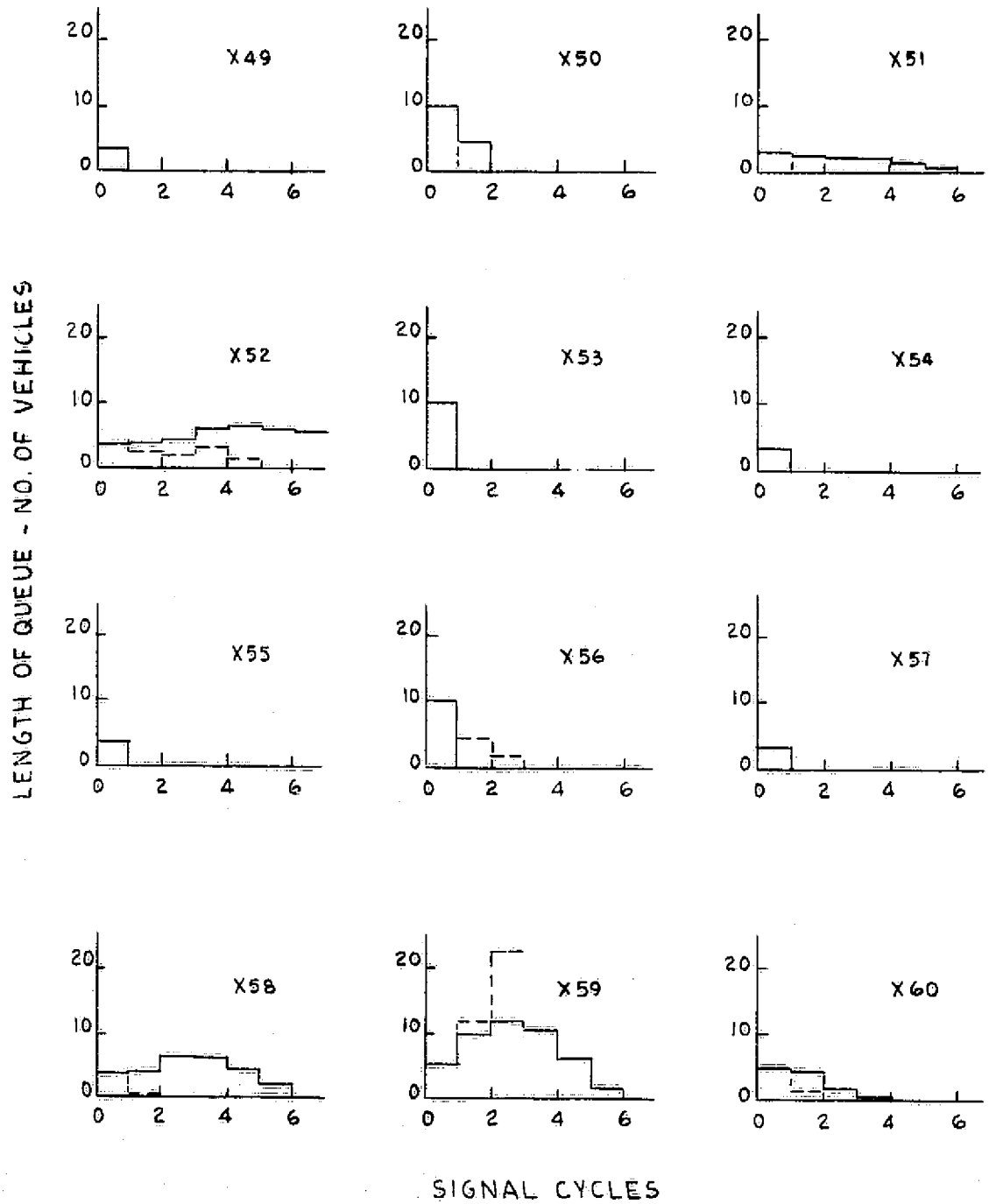


Figure 7-7(d). - Continued.

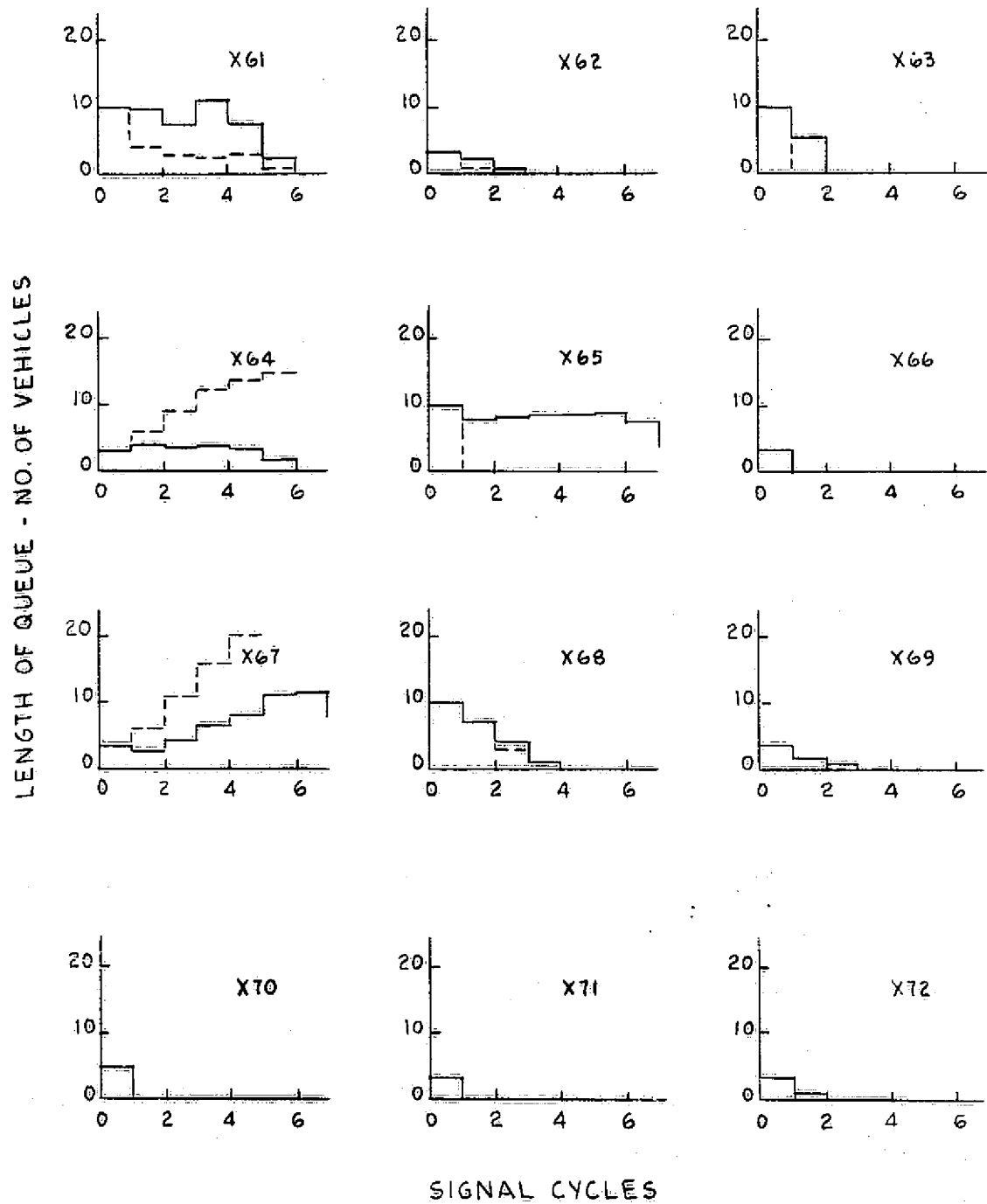


Figure 7-7(e). - Continued.

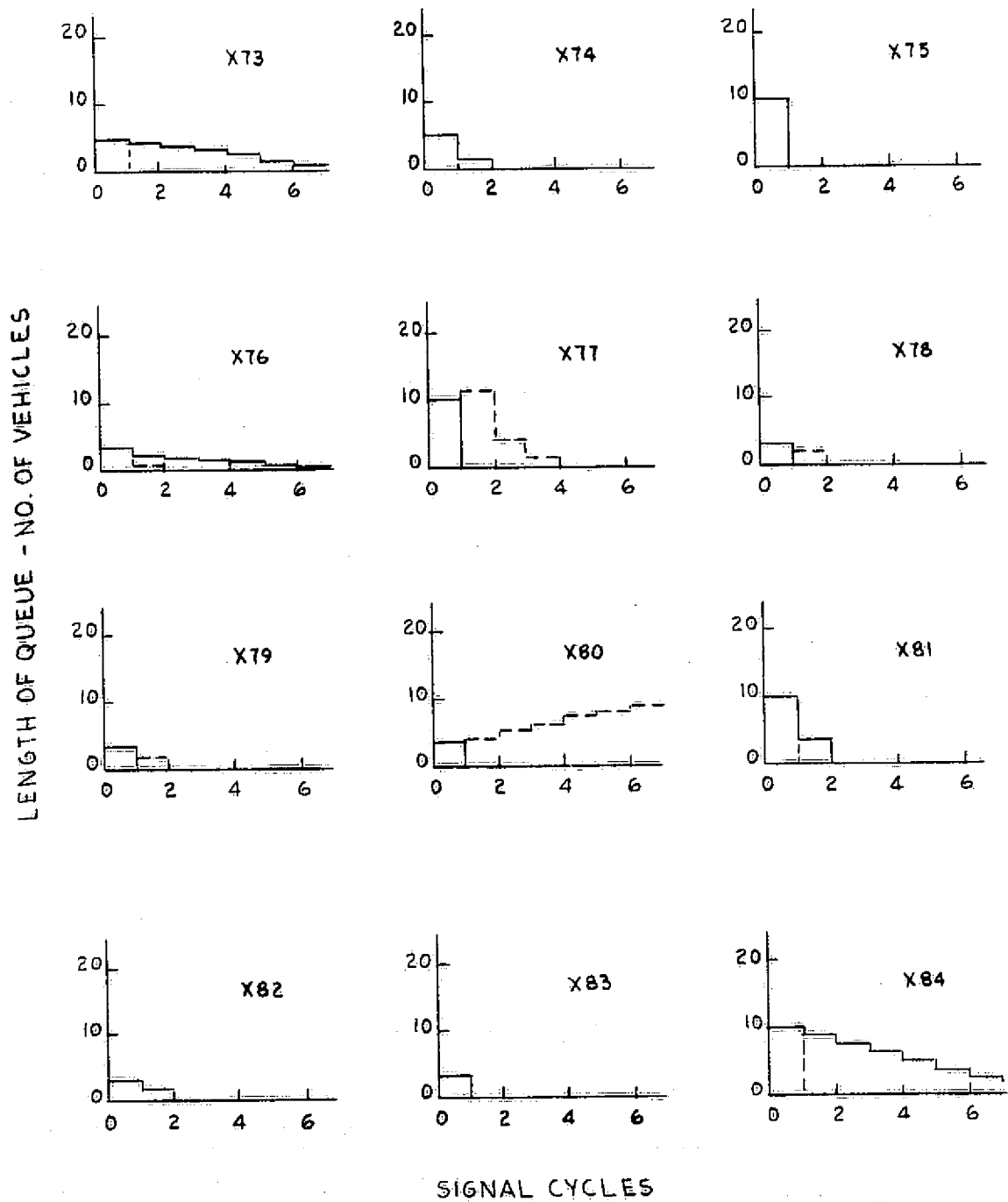


Figure 7-7(f). - Continued.

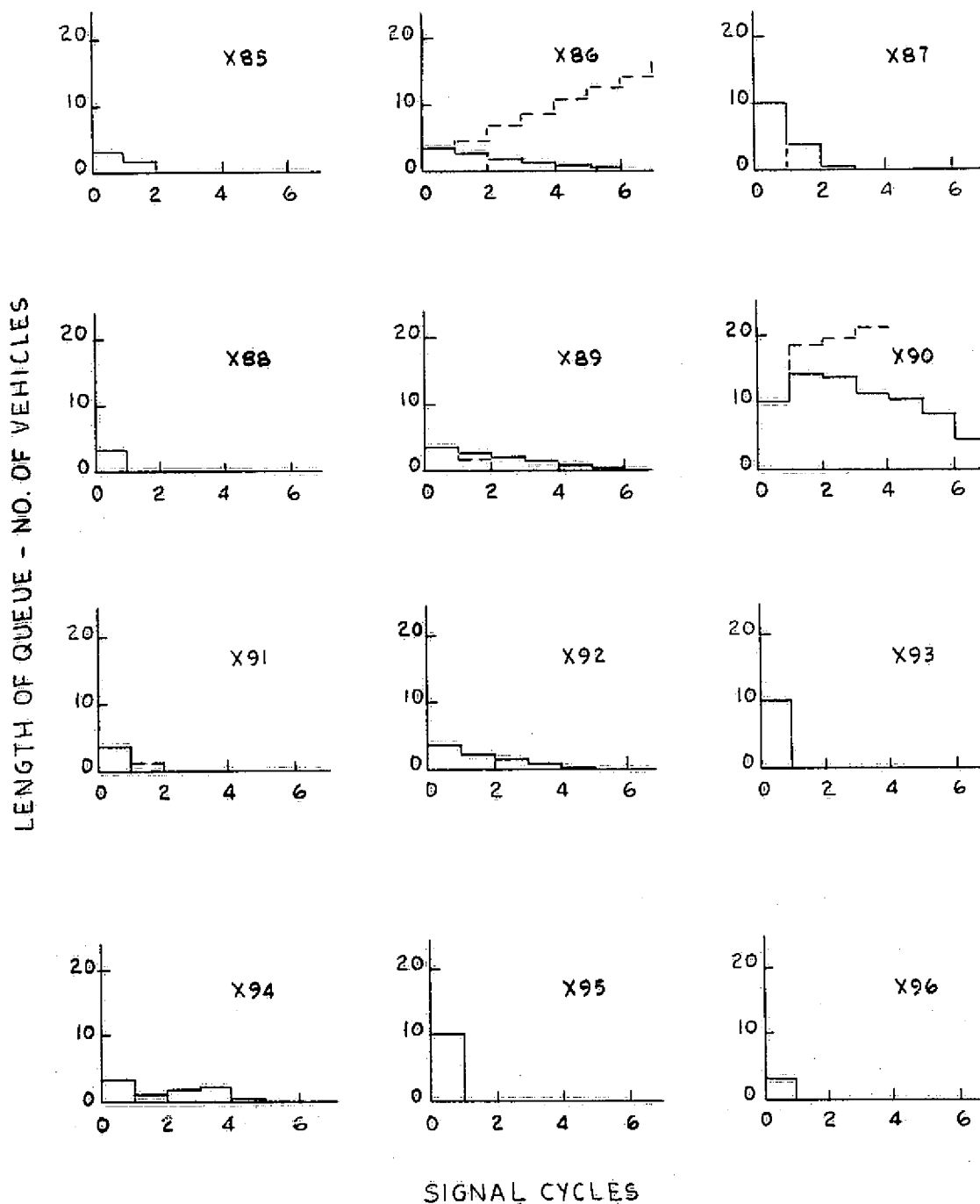


Figure 7-7(g). - Continued.

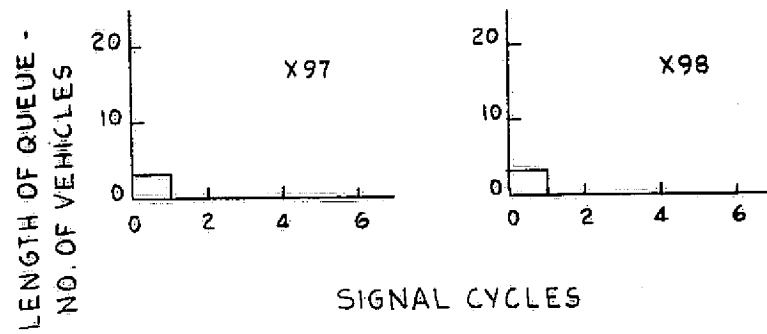


Figure 7-7(h). - Concluded.

a higher flow must be accommodated, all queues are effectively cleared and the links are restored and maintained at nominal conditions.

The Toledo traffic signal settings adequately eliminate congestion and clear most of the queues effectively. The critical queues (X59, X64, X67) increase to congestion levels and cannot clear until the traffic inflow to these queues is reduced. In addition Dorr-Reynolds LT (X22), Nebraska-Byrne LT (X80), Hill-Byrne LT (X86), and Byrne-Hill S-B (X90) are all problem areas. With these signal settings, congestion could occur at these intersections.

## 7.2 Results for Section II

The topology of section II is illustrated in figure 7-8 and consists of an area bounded by Airport Highway, Byrne and Detroit. The network was modeled using the same method and assumptions described for section I. The Toledo traffic system was established with necessary modifications to improve the traffic flow through the network. The intersections and vehicle queues are numerically identified in figures 7-9 to 7-9(b). Several intersections within this area are slightly more complex because of the requirement for multiple entrances and exits. This situation accounts for the larger number of queues.

The proposed traffic signal settings are presented in table 7-2 to 7-2(a) for three time intervals. These signal settings effectively control the traffic flow within the network and minimize the delay at the intersections. The assumption of a constant green band for left turns is also applicable, except wherever the traffic flow dictates a variable signal setting. As can be noted from tables 7-2 to 7-2(a) and the accompanying signal phasing diagrams (figs. 7-10 to 7-10(j)), the control settings for the first two intervals are identical, except for



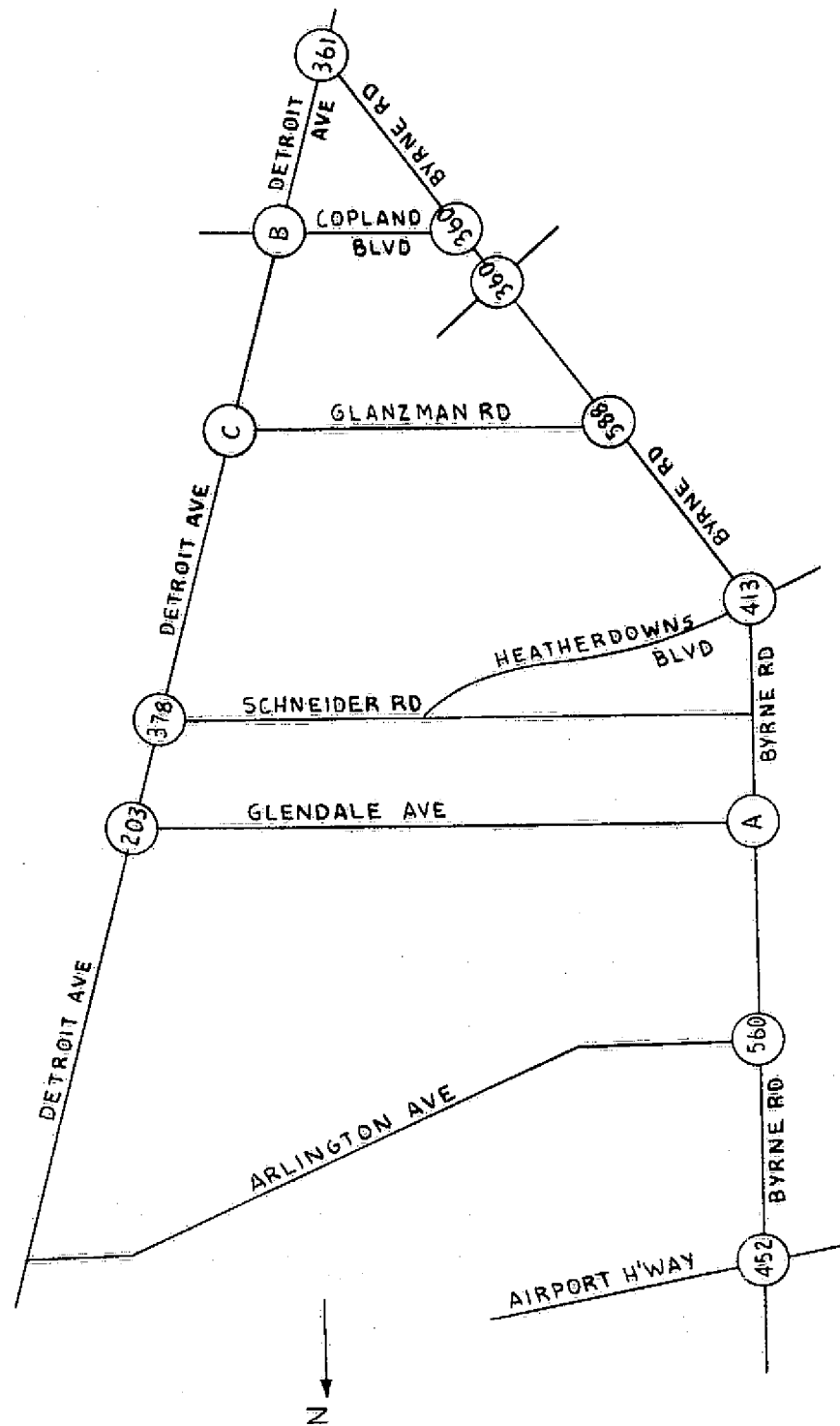


Figure 7-8. - Traffic network - Section II.

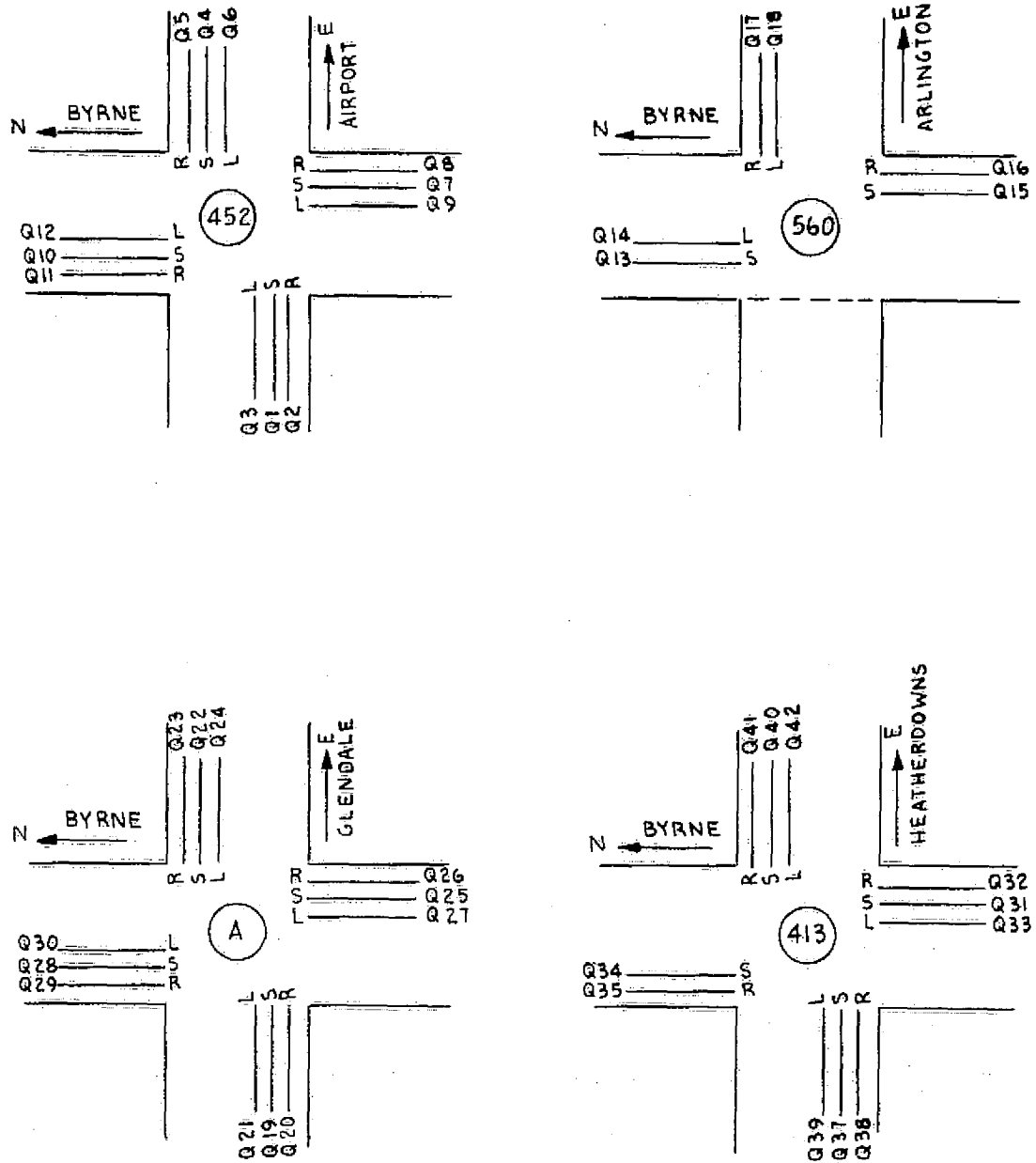


Figure 7-9. - Identification of intersections and queues, Section II.



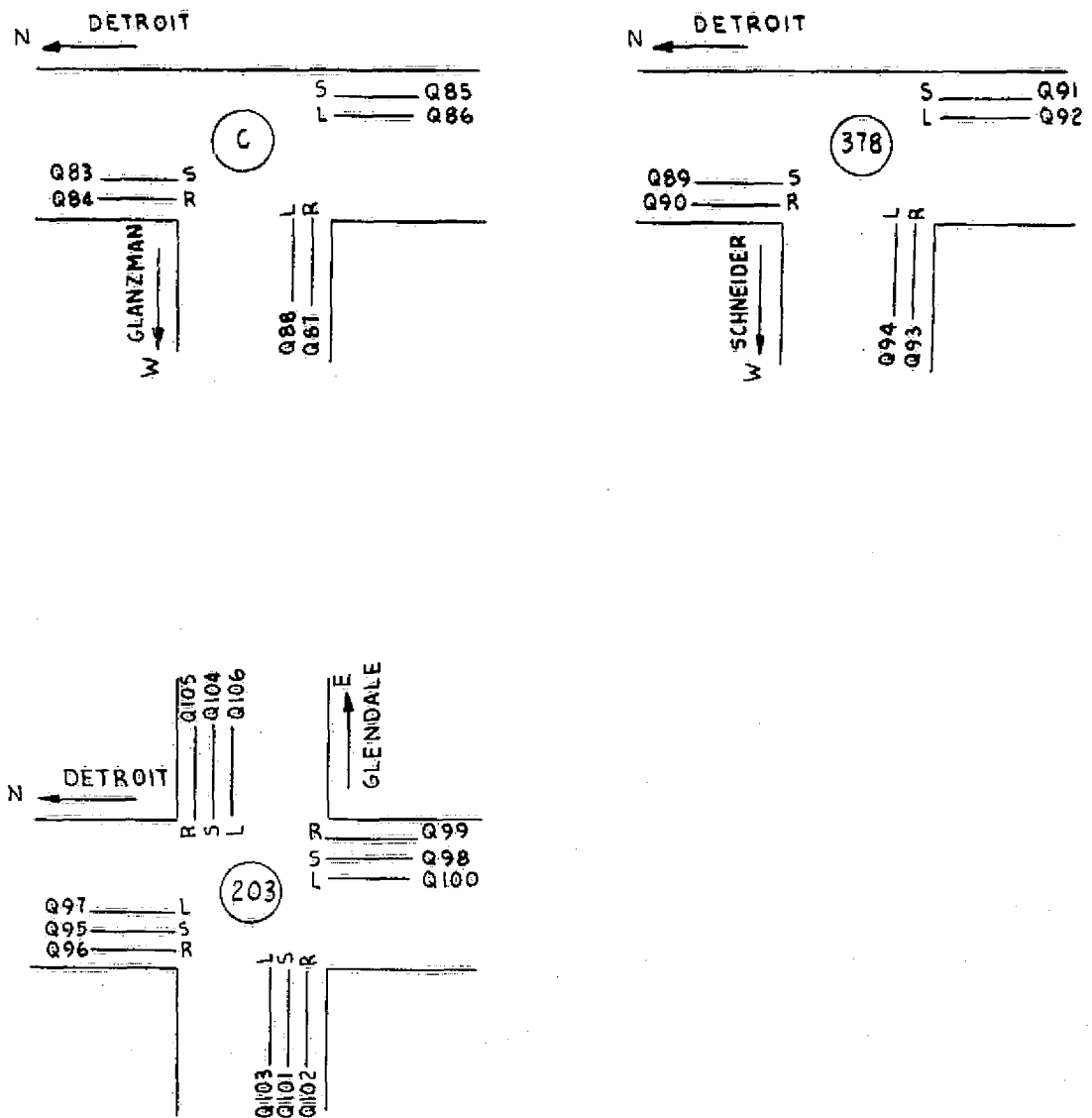


Figure 7-9(b). - Concluded.

TABLE 7-2. - CONTROL SETTINGS - SECTION II

Control	7-9 a.m.	11-1 p.m.	3-6 p.m.
U1	0.154	0.154	0.140
U1A	.232	.232	.166
DEL1	.150	.150	.175
U2	.720	.720	.800
DEL2	.350	.350	.375
U3	.330	.330	.338
U3A	.113	.113	.103
DEL3	.225	.225	.300
U4	.466	.466	.532
U4A	.305	.305	.230
DEL4	.100	.100	.100
U5	.289	.289	.270
DEL5	.250	.250	.275
U6	.598	.598	.722
DEL6	.250	.250	.250
U6B	.724	.742	.692
U7	.563	.563	.422
DEL7	.250	.250	.250
U8	.376	.376	.445
DEL8	.150	.150	.150
U9	.421	.421	.462
DEL9	.100	.100	.100
U10	.484	.484	.523
DEL10	.100	.100	.100
U11	.313	.313	.248
U11A	.173	.201	.284
DEL11	.150	.150	.150
P	.684	1.28	5.69

**Definition:**

U1            Intersection #452 Airport Highway  
 U1A          Left turn Airport=Byrne  
 DEL1        Left turn Byrne-Airport Highway  
 U2            Intersection #360-Byrne

TABLE 7-2(a). - CONTROL SETTINGS - SECTION II

DEL2	Left turn Byrne-Arlington
U3	Intersection Byrne-Glendale
U3A	Left turn Byrne-Glendale
DEL3	Left turn Glendale-Byrne
U4	Intersection #413 Byrne
U4A	Left turn Heatherdowns-Byrne
DEL4	Left turn Byrne-Heatherdowns
U5	Intersection #588 Byrne-Glanzman
DEL5	Left turn Byrne-Winston-Glanzman
U6	Intersection #360 Byrne
U6B	Intersection #360 Byrne
DEL6	Left turn Byrne-Copland
U7	Intersection #361 Detroit
DEL7	Left turn Detroit-Byrne-Devonshire
U8	Intersection Detroit-Copland
DEL8	Left turn Detroit-Copland
DEL8	Left turn Copland-Detroit
U9	Intersection Detroit-Glanzman
DEL9	Left turn Detroit-Glanzman
U10	Intersection #378 Detroit-Schneider
DEL10	Left turn Detroit-Schneider
U11	Intersection #203 Detroit-Glendale
U11A	Left turn Glendale-Detroit
DEL11	Left turn Detroit-Glendale

Byrne-Copland main stream traffic and Glendale-Detroit LT. Due to the higher flow for the 3-6 p.m. interval, the control settings differ from those derived for the preceding sessions. In some instances, a larger left turn green band is necessary to move the traffic.

A chart describing a typical phasing plan for each intersection is illustrated in figures 7-10 to 7-10(j). The diagram indicates the magnitudes (in terms of cycle time) and the timing sequence of the control variables. For intersection #560, the signal phasing diagram (fig. 7-10(a)) indicates a phase lag approach whereby the Byrne N-B traffic is stopped to allow the Byrne-Arlington LT traffic to proceed. The Byrne S-B traffic is uninterrupted during the entire green band. The remainder of the cycle time is used for the Arlington-Byrne left and right turn traffic. The diagrams indicate the duration and start of the green band for each direction of flow. Unless specified, right turns are generally assumed to proceed with the main stream traffic. The principle employed for the timing sequence is to synchronize the traffic signals along Byrne Road and Detroit Avenue. The traffic along access routes receives a red band. However, since heavy traffic flow is assumed the arriving platoons must wait for other vehicles to proceed through the intersection.

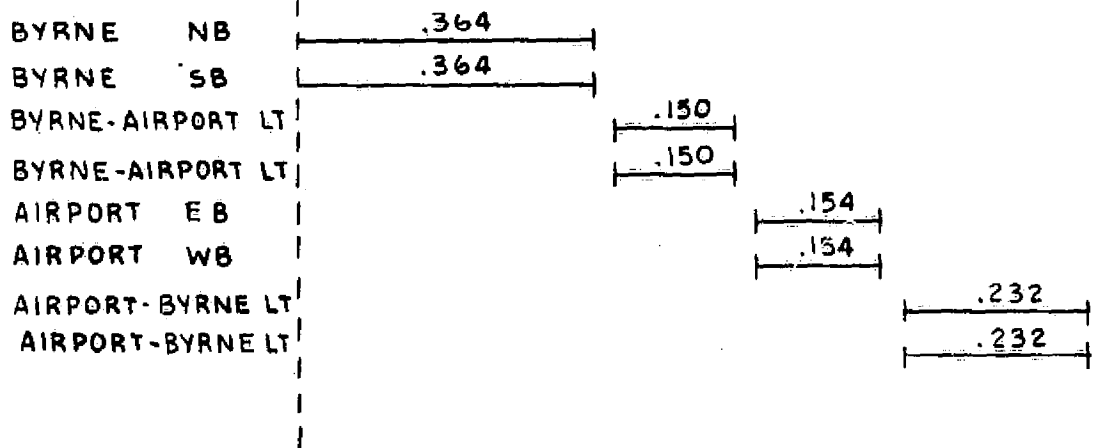
A progression timing plan for Byrne and Detroit S-B directions is presented in figures 7-11 and 7-11(a). The offset between the intersections was computed from the travel time data supplied by the traffic engineer.

The proposed signal settings were used to compute the behavior of the vehicle queues at each intersection. The results of the analysis are shown in figures 7-12 to 7-14(h) for the specified time intervals.

CYCLE TIME: 90 SEC.

TIME OF DAY: 7-9 a.m.

11-1 p.m.



TIME OF DAY: 3-6 p.m.

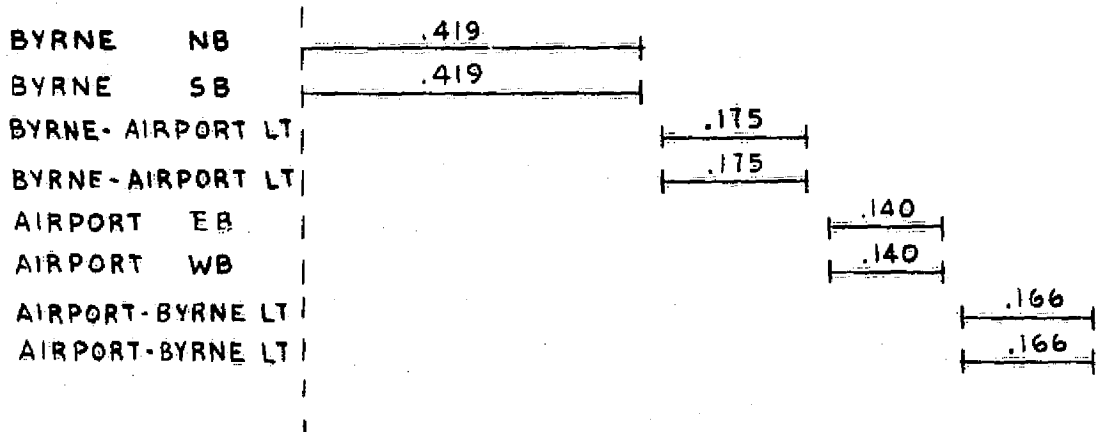
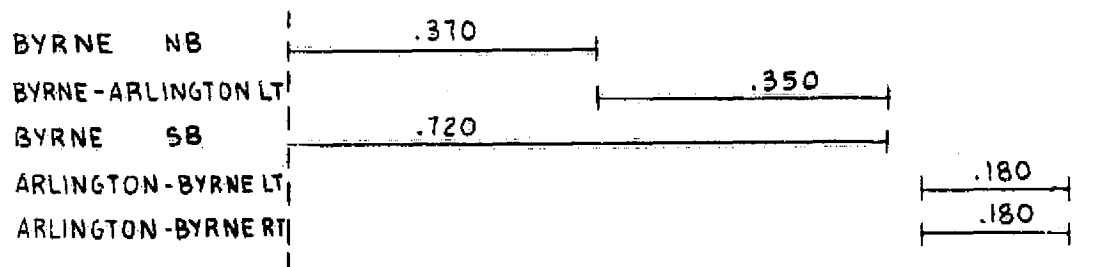


Figure 7-10. - Signal phasing - No. 452, Byrne-Airport.



CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

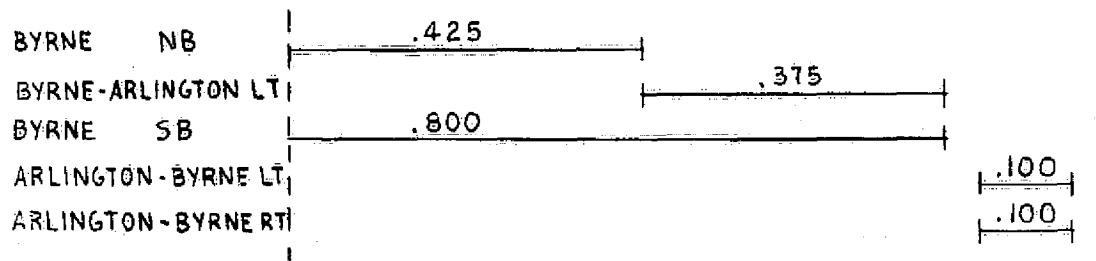
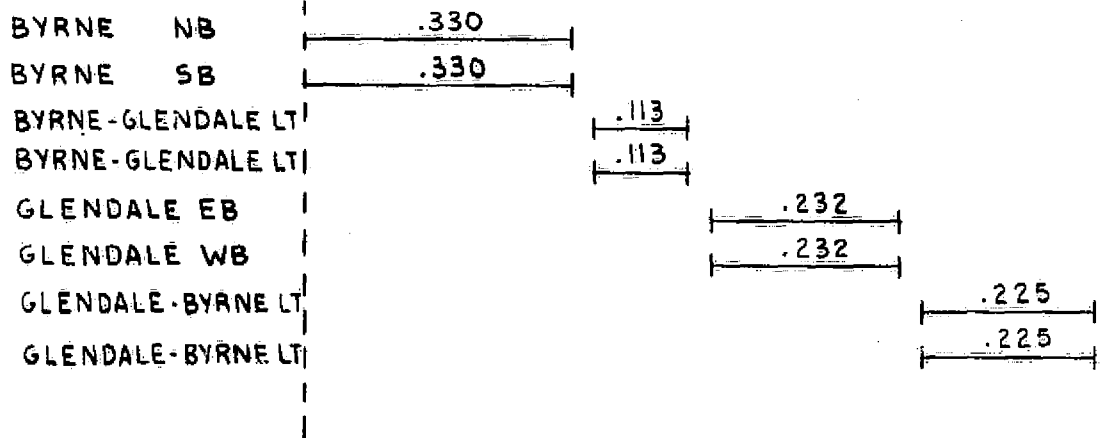


Figure 7-10(a). - Signal phasing - No. 560, Byrne-Arlington.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

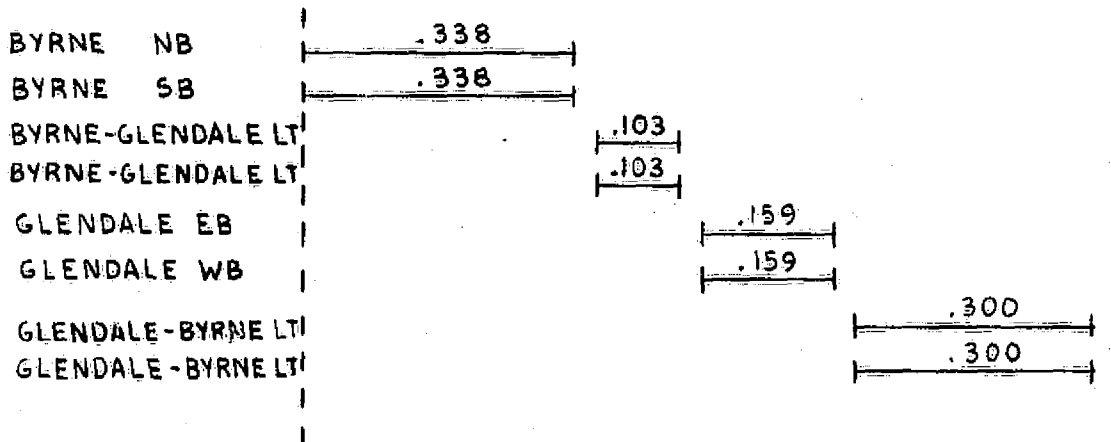
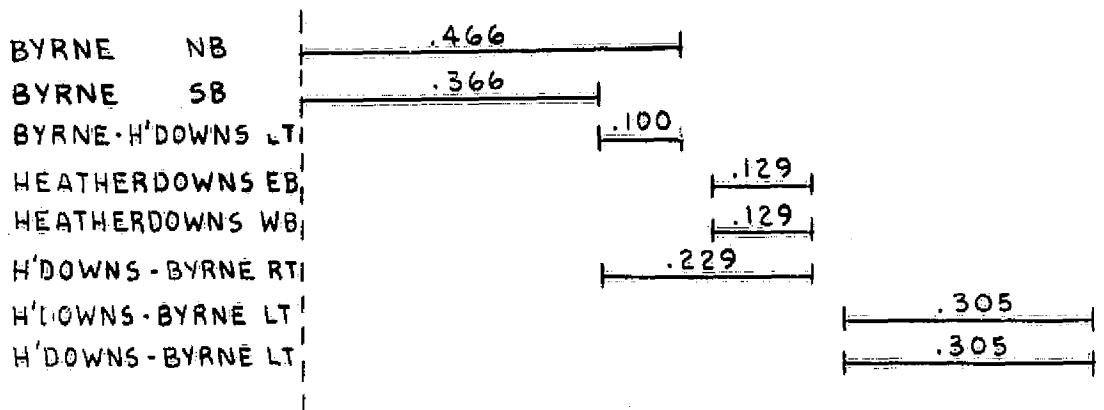


Figure 7-10(b). - Signal phasing - Byrne-Glendale.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

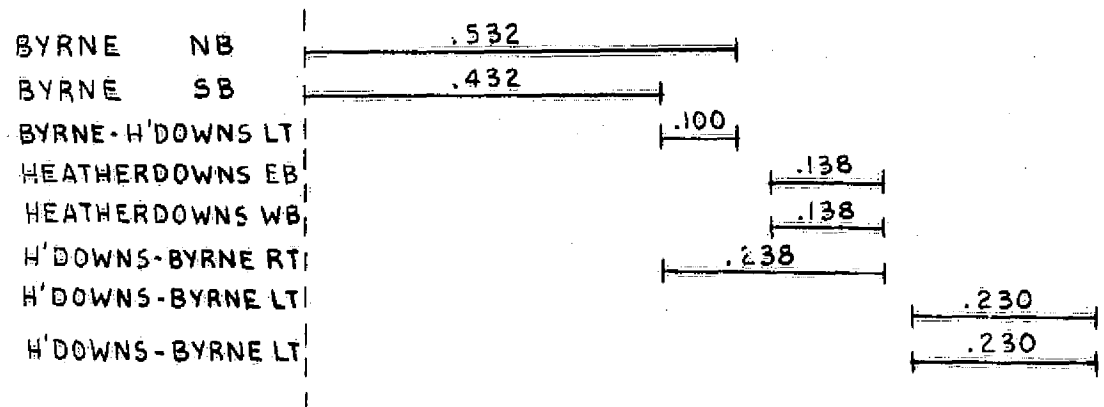
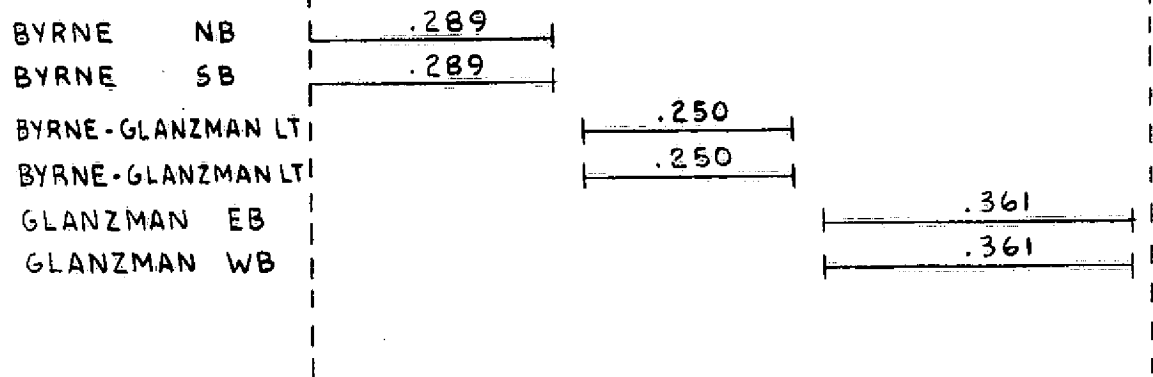


Figure 7-10(c). - Signal phasing - No. 413, Byrne-Heatherdowns.

CYCLE TIME: 90 SEC.

TIME OF DAY: 7-9 a.m.

11-1 p.m.



TIME OF DAY: 3-6 p.m.

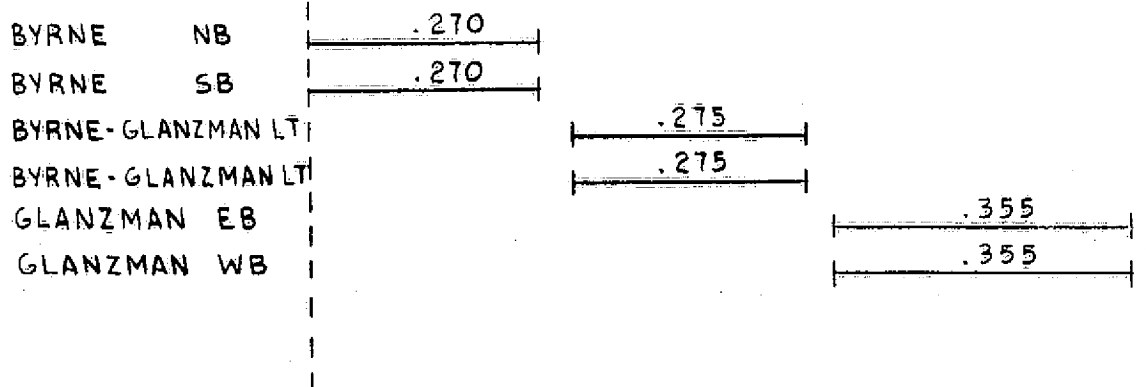
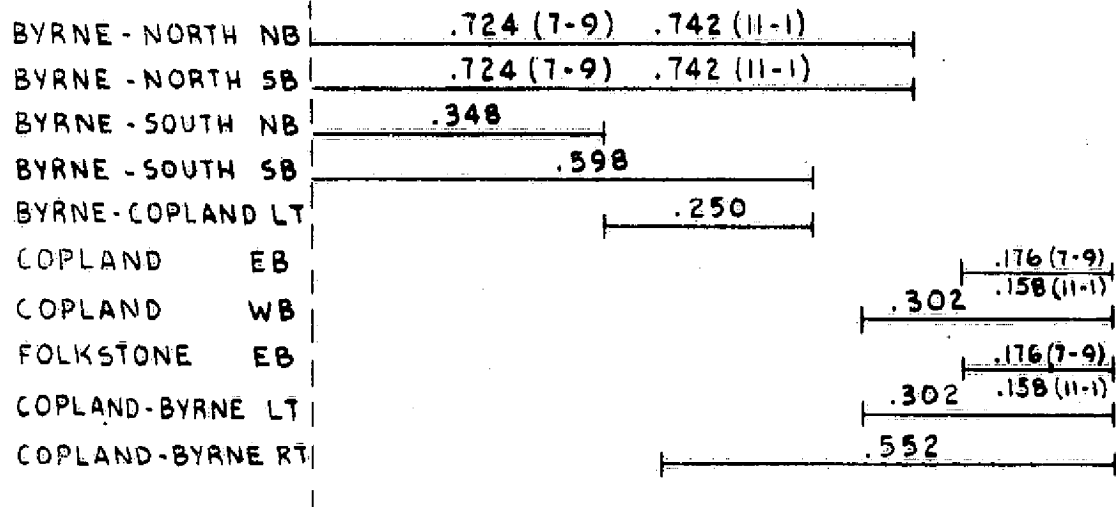


Figure 7-10(d). - Signal phasing - No. 588, Byrne-Glanzman.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

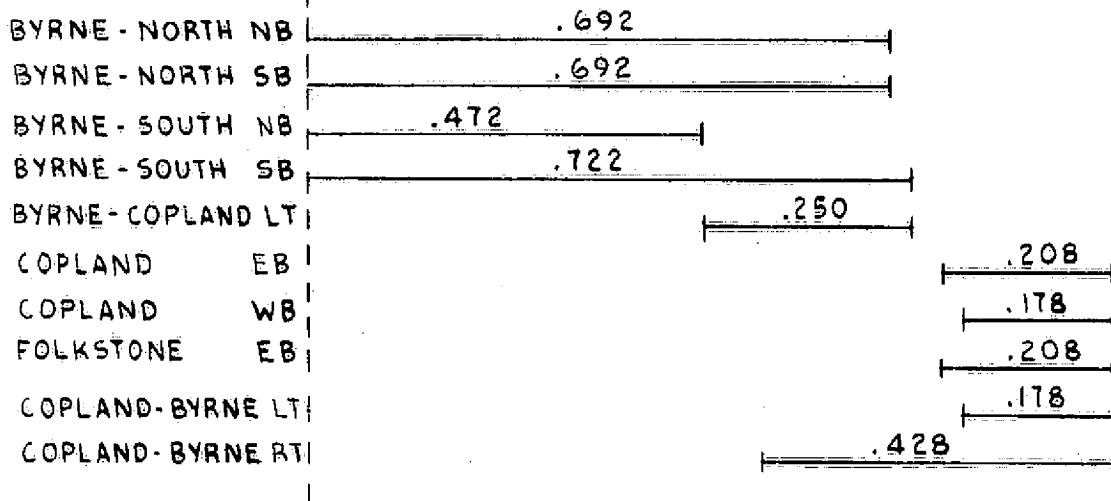
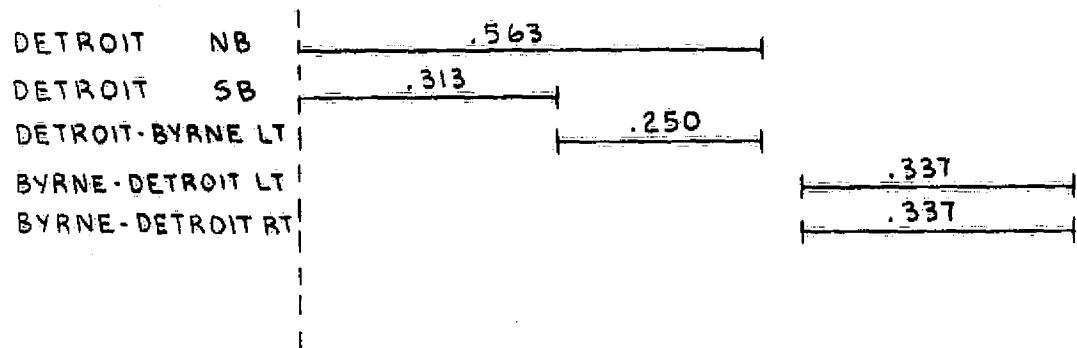


Figure 7-10(e). - Signal phasing - No. 360, Byrne-Folkstone-Copland.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

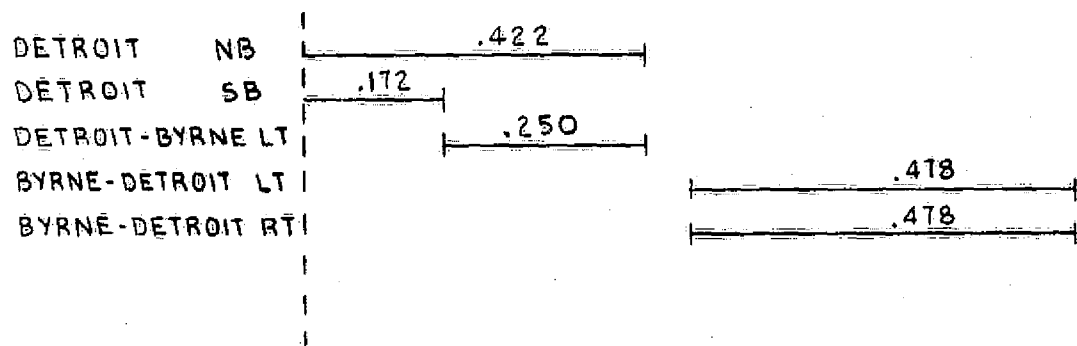
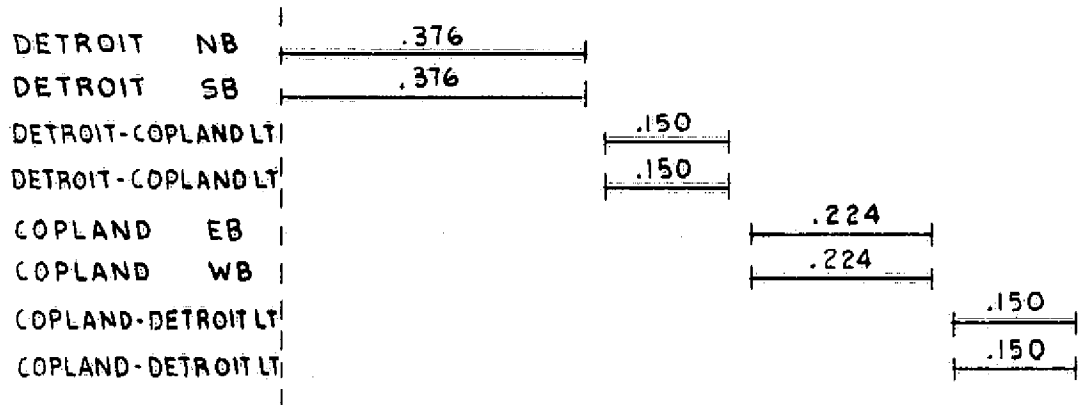


Figure 7-10(f). - Signal phasing - No. 361, Detroit-Byrne.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

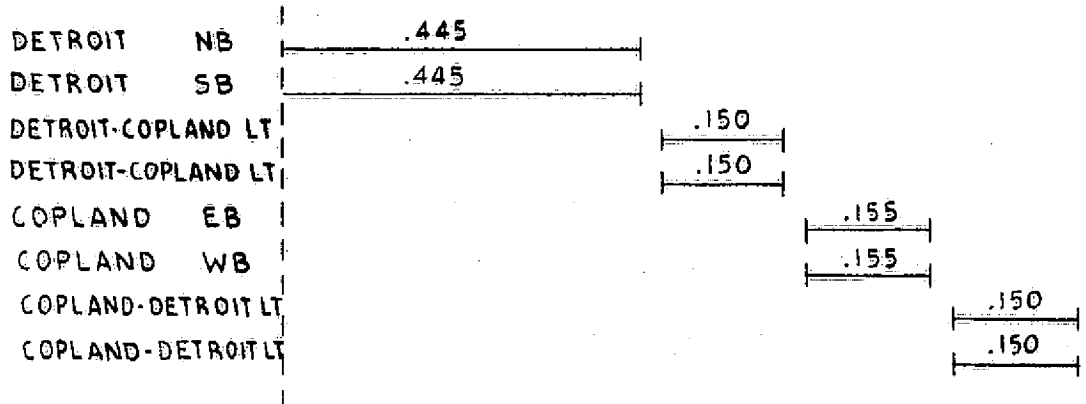
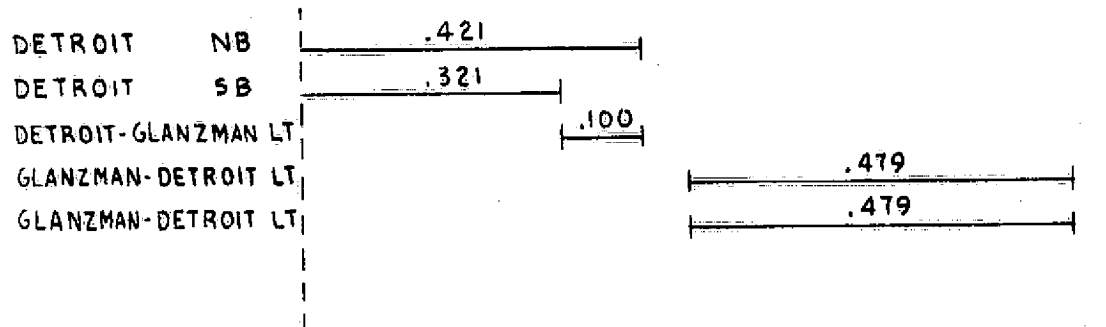


Figure 7-10(g). - Signal phasing - Detroit-Copland.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

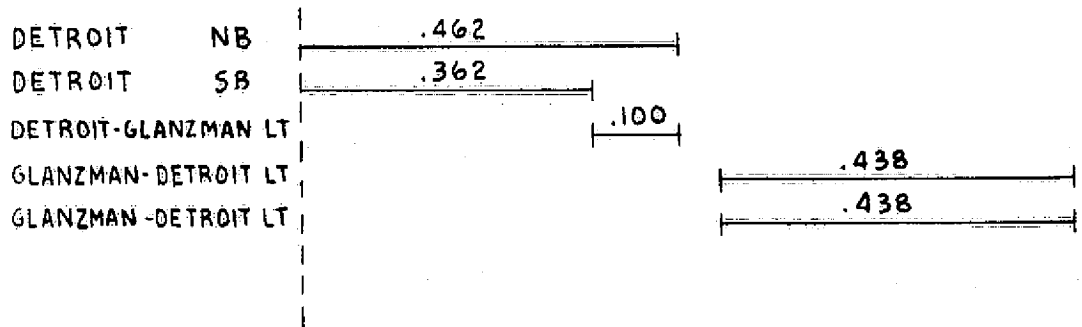
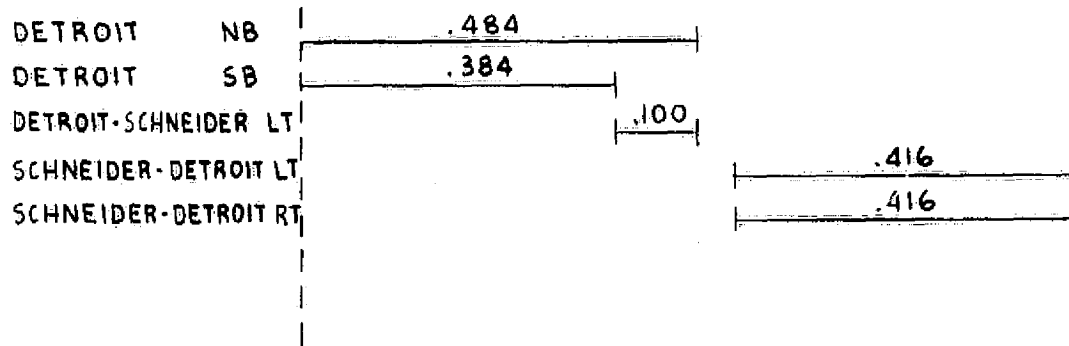


Figure 7-10(h). - Signal phasing - Detroit-Glanzman.



CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

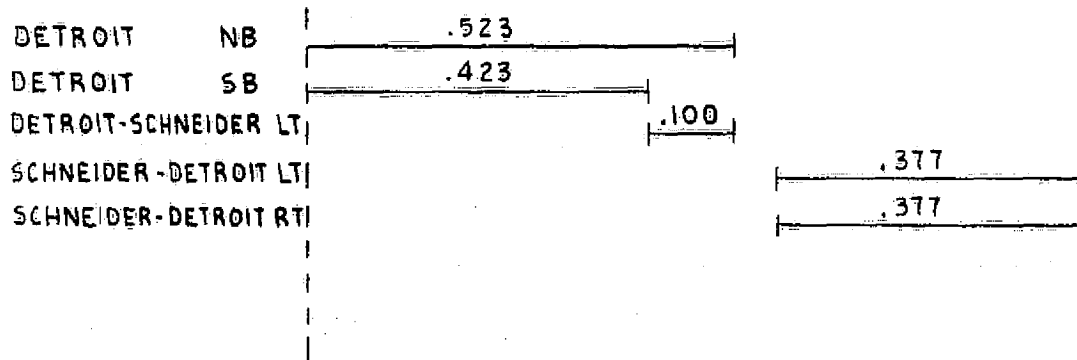
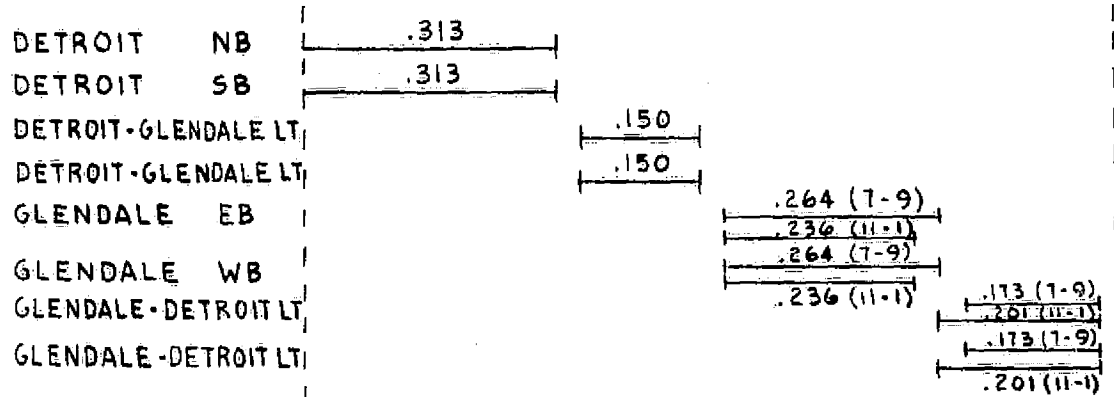


Figure 7-10(1). - Signal phasing - No. 378, Detroit-Schneider.

CYCLE TIME: 90 SEC.  
 TIME OF DAY: 7-9 a.m.  
 11-1 p.m.



TIME OF DAY: 3-6 p.m.

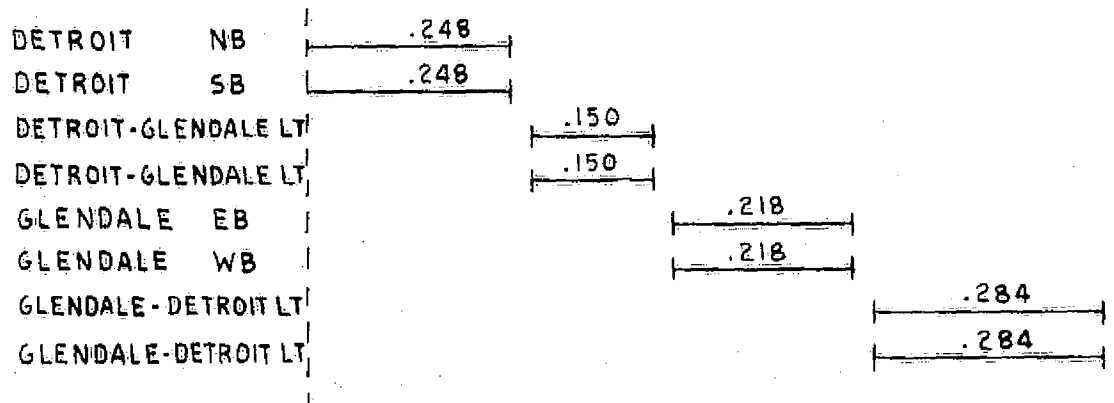


Figure 7-10(j). - Signal phasing - No. 203, Detroit-Glendale.

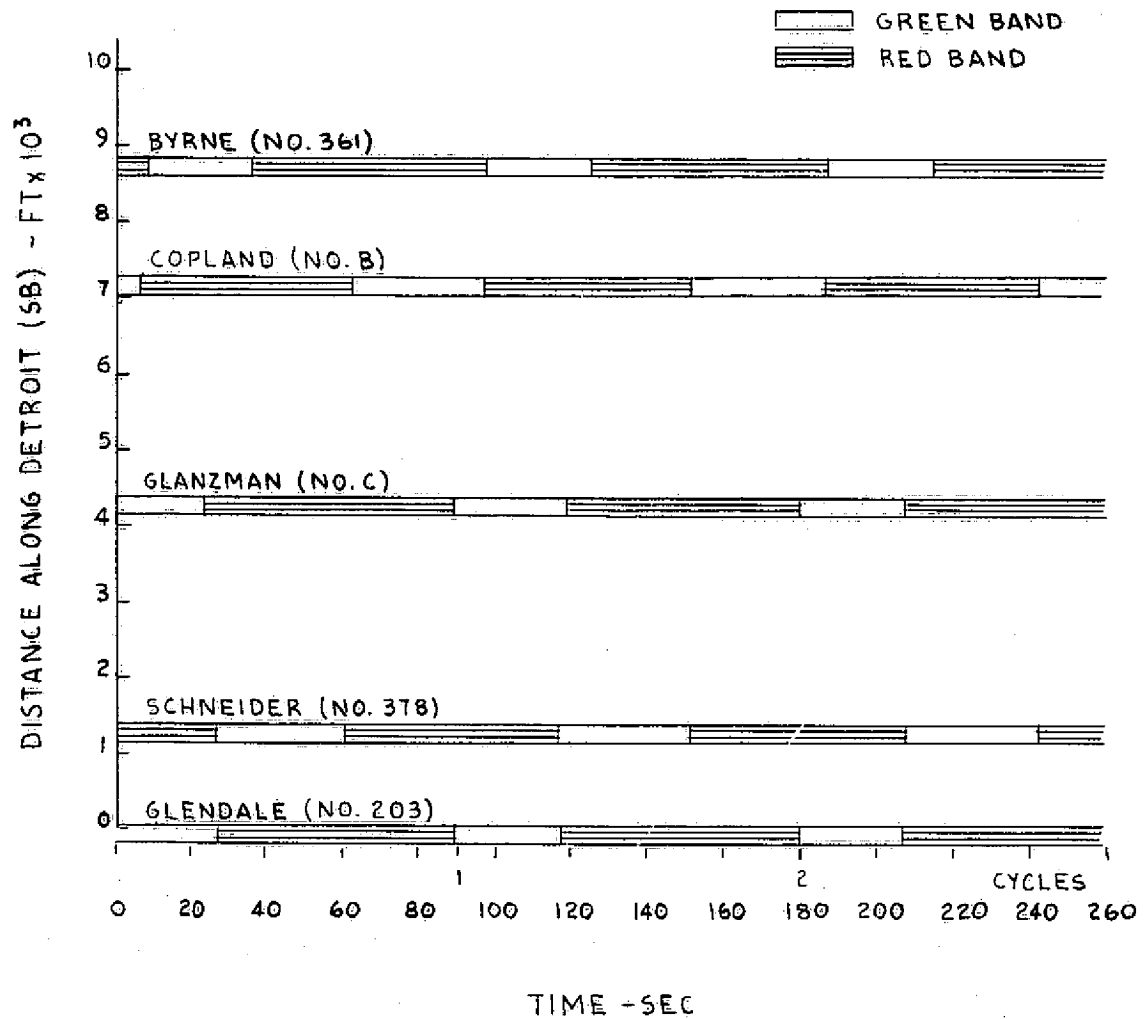


Figure 7-11. - Timing for traffic signals along Detroit Ave., Section II,  
direction: southbound, time of day: 7-9 a.m., 11-1 p.m.

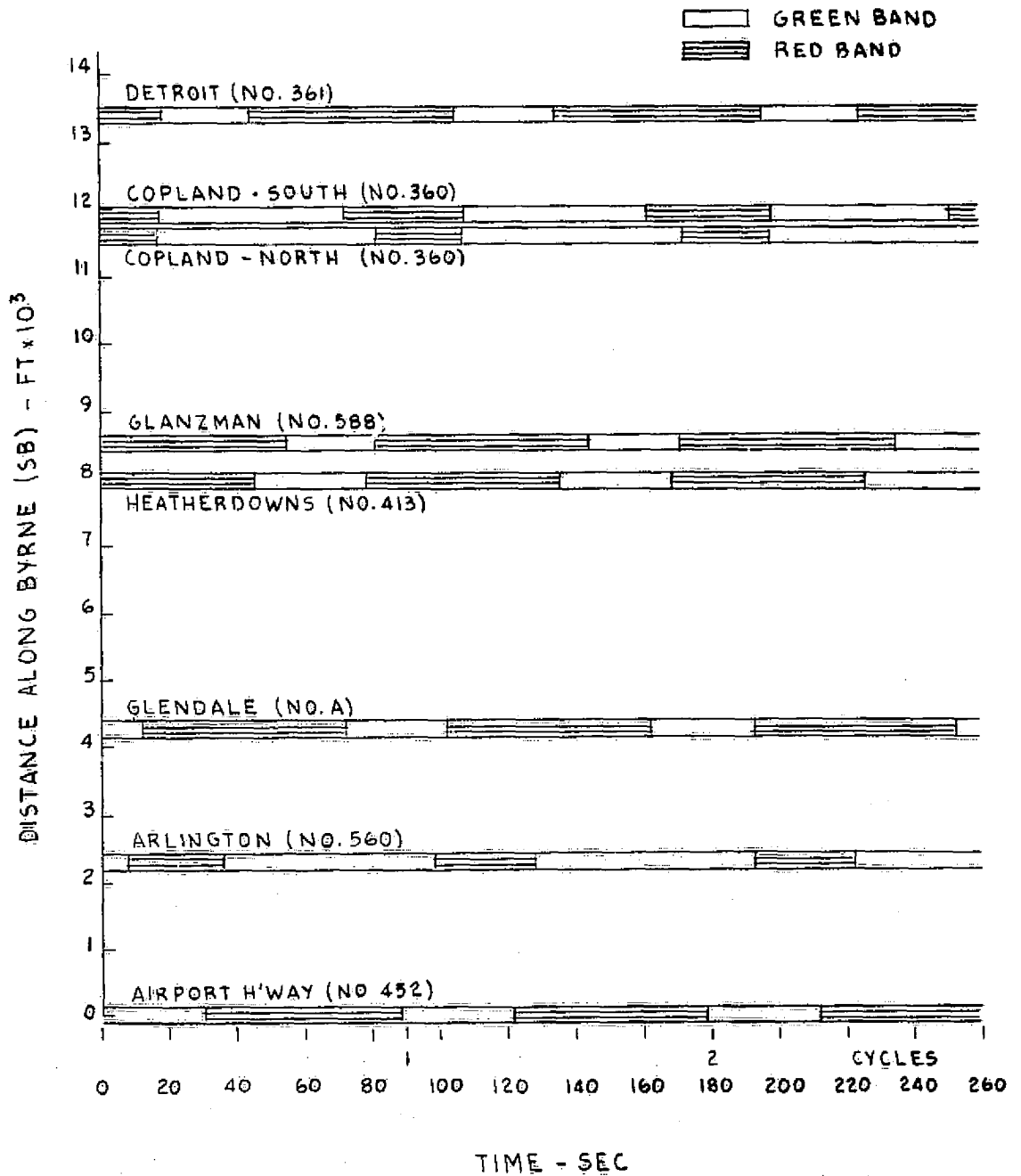


Figure 7-11(a). - Timing for traffic signals along Byrne Rd., Section II, direction: southbound, time of day: 7-9 a.m., 11-1 p.m.

As mentioned previously, these graphs illustrate the average behavior of the vehicle queues and conditions at the end of each signal cycle. The results for the proposed and Toledo signal settings are presented in figures 7-12 to 7-12(h) for the 7-9 a.m. interval. The results for the proposed signal settings indicate that for the assumed traffic inflow and initial conditions, the vehicle queues remain stable and reduce within several signal cycles. Several queues exhibit an increase after one to two cycles, a result which is caused by the delayed platoons discharged from neighboring intersections. Selected queues that could cause difficulties are Byrne-Arlington N-B (X15), Byrne-Glendale N-B (X25), Byrne-Glanzman LT (X48), Glanzman-Byrne RT (X52), Byrne-Detroit RT (X65), Detroit-Byrne S-B (X69), Detroit-Glanzman N-B (X86), Detroit-Glendale N-B (X98), Detroit-Glendale RT (X99), and Glendale-Detroit E-B (X101). These queues (approx. 10%) remain at high levels for several cycles. but they are then cleared within nine cycles. The long lines will be annoying because they require drivers to wait for a few cycles before proceeding through an intersection. The initial queue lengths might also be pessimistic, so that there could be fewer vehicles waiting at these intersections. The Byrne-Folkstone-Copland intersection (#360) is of interest to the traffic engineer since the two signals are separated by seventy feet, thus requiring link constraints. The results showing the behavior of these queues (X53 - X64) indicate that congestion should not be experienced at this intersection.

The section II network was modeled to correspond closely with regulations of the Toledo traffic engineer. The results (dotted lines) (figs. 7-12 to 7-12(h)) illustrate that the control settings effec-

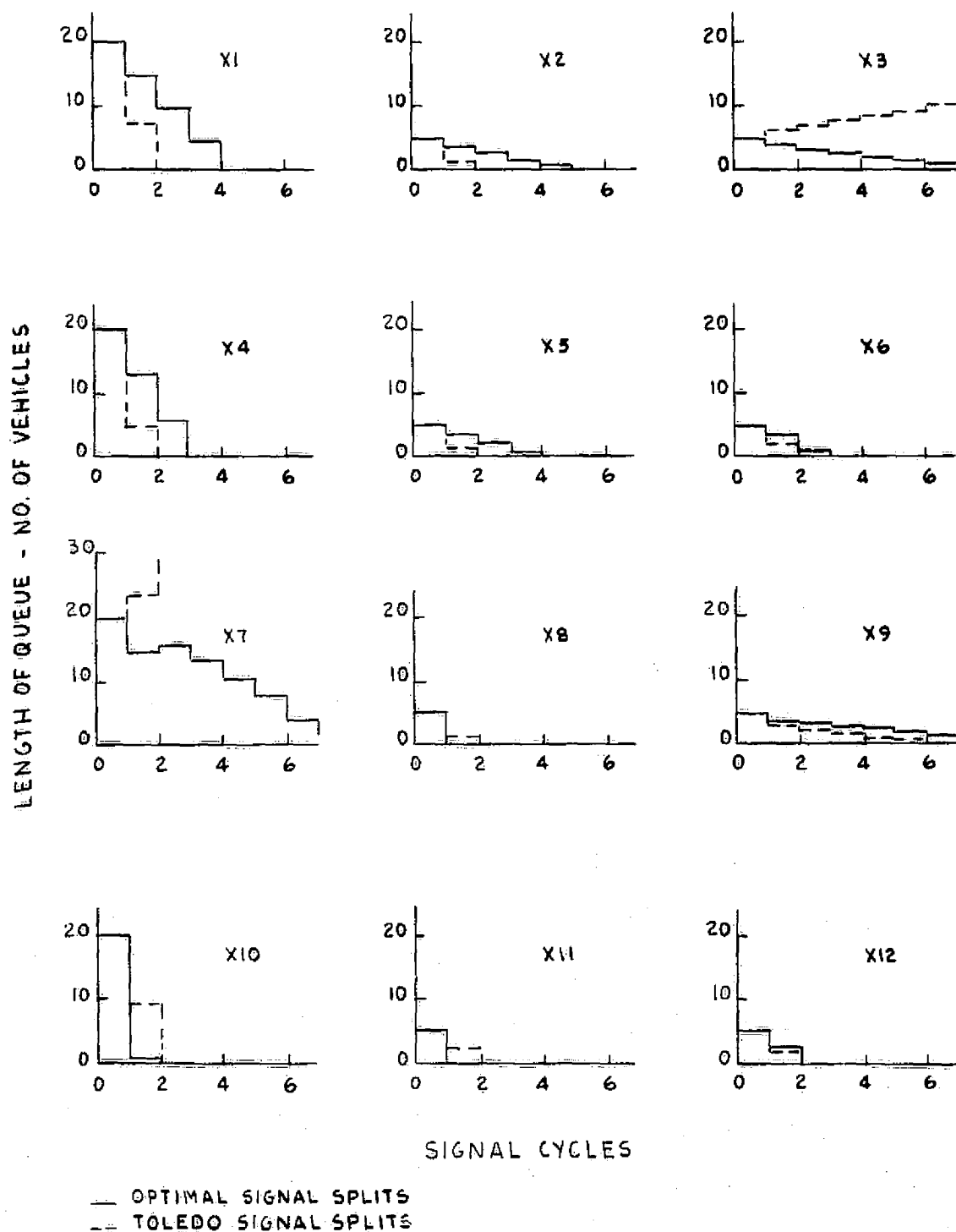


Figure 7-12. - Dissipation of vehicle queues, Section II, 7-9 a.m.

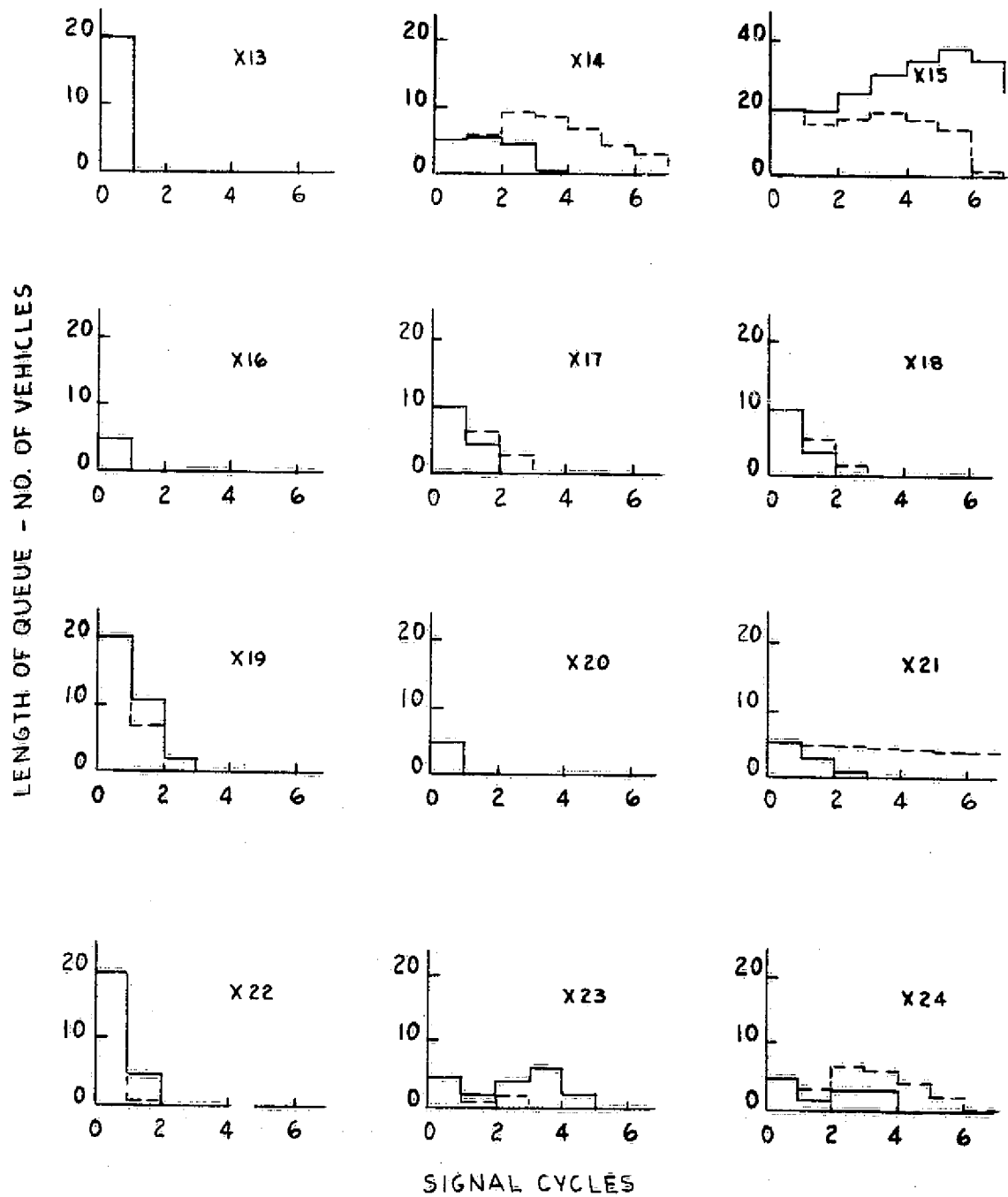


Figure 7-12(a). - Continued.

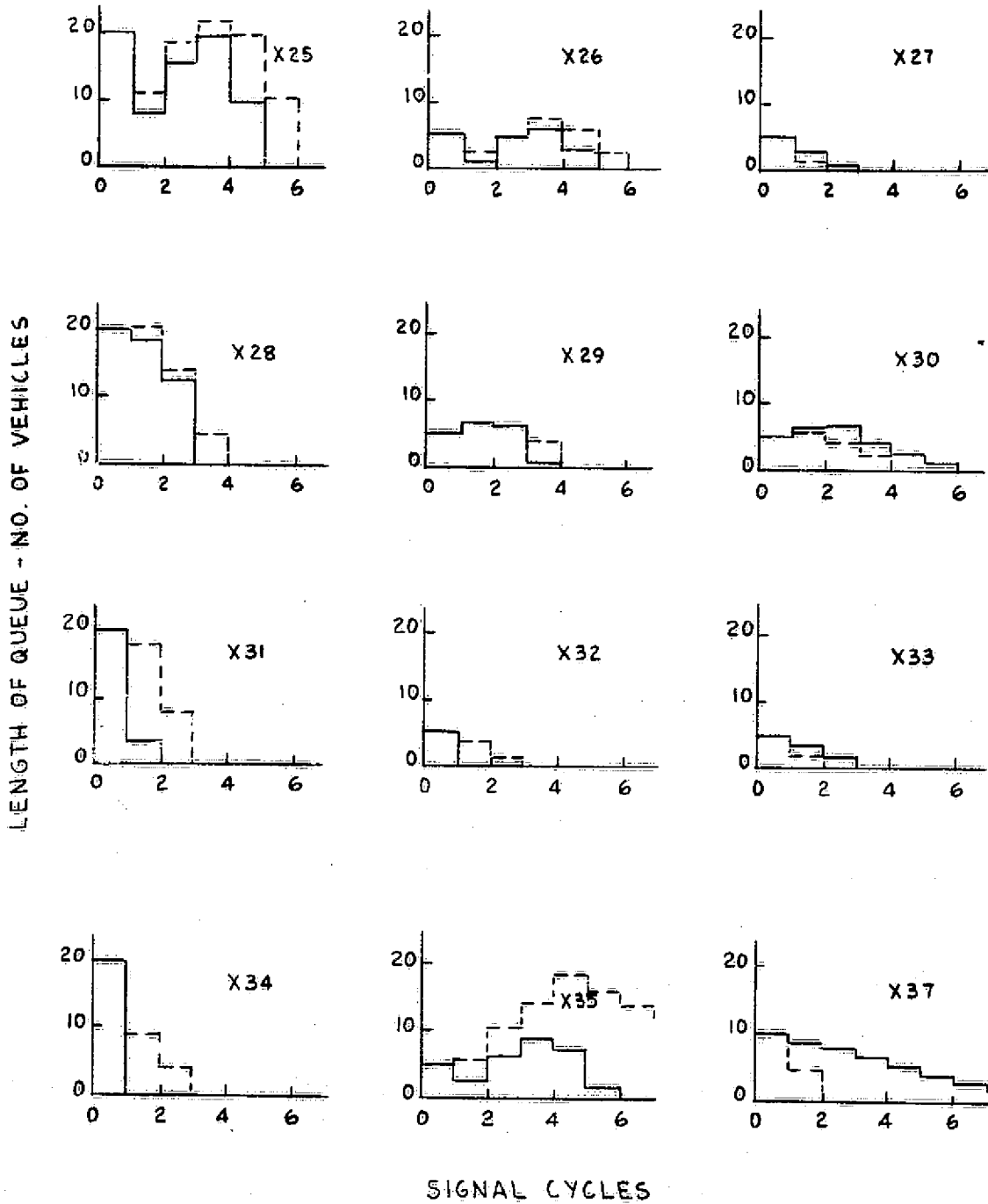


Figure 7-12(b). - Continued.



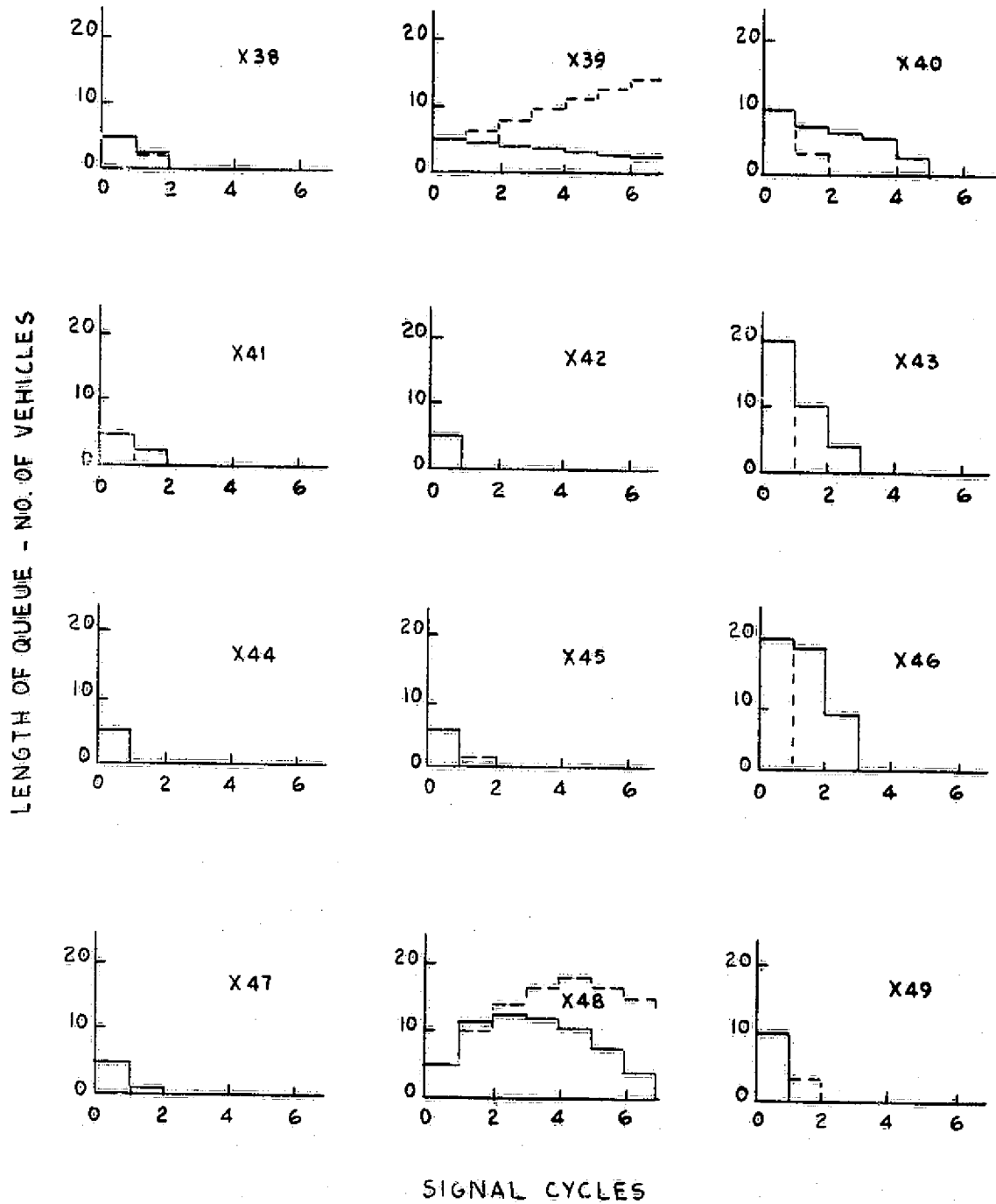
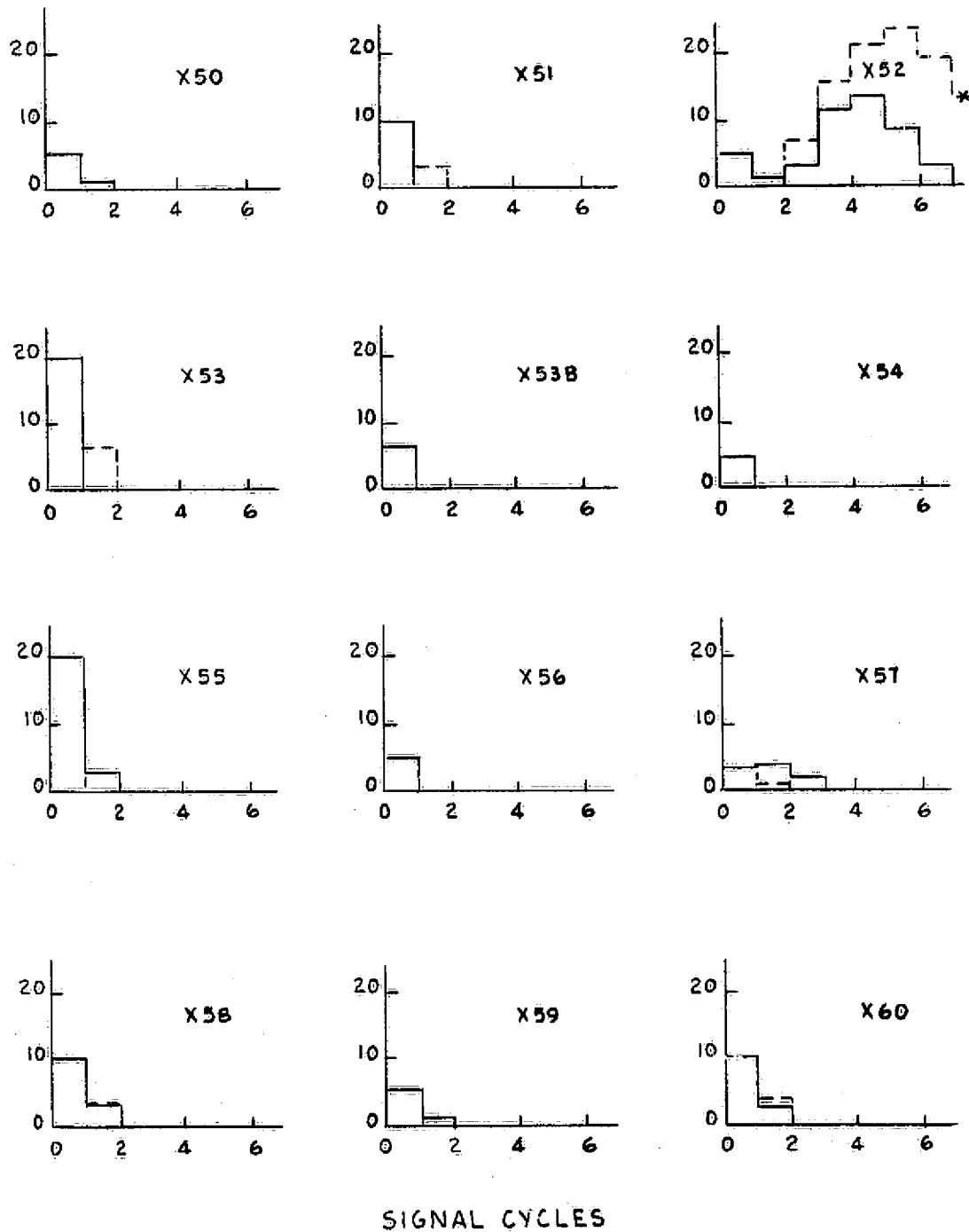


Figure 7-12(c). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



\* QUEUE REDUCES TO ZERO  
AFTER NINTH CYCLE

Figure 7-12(d). - Continued.

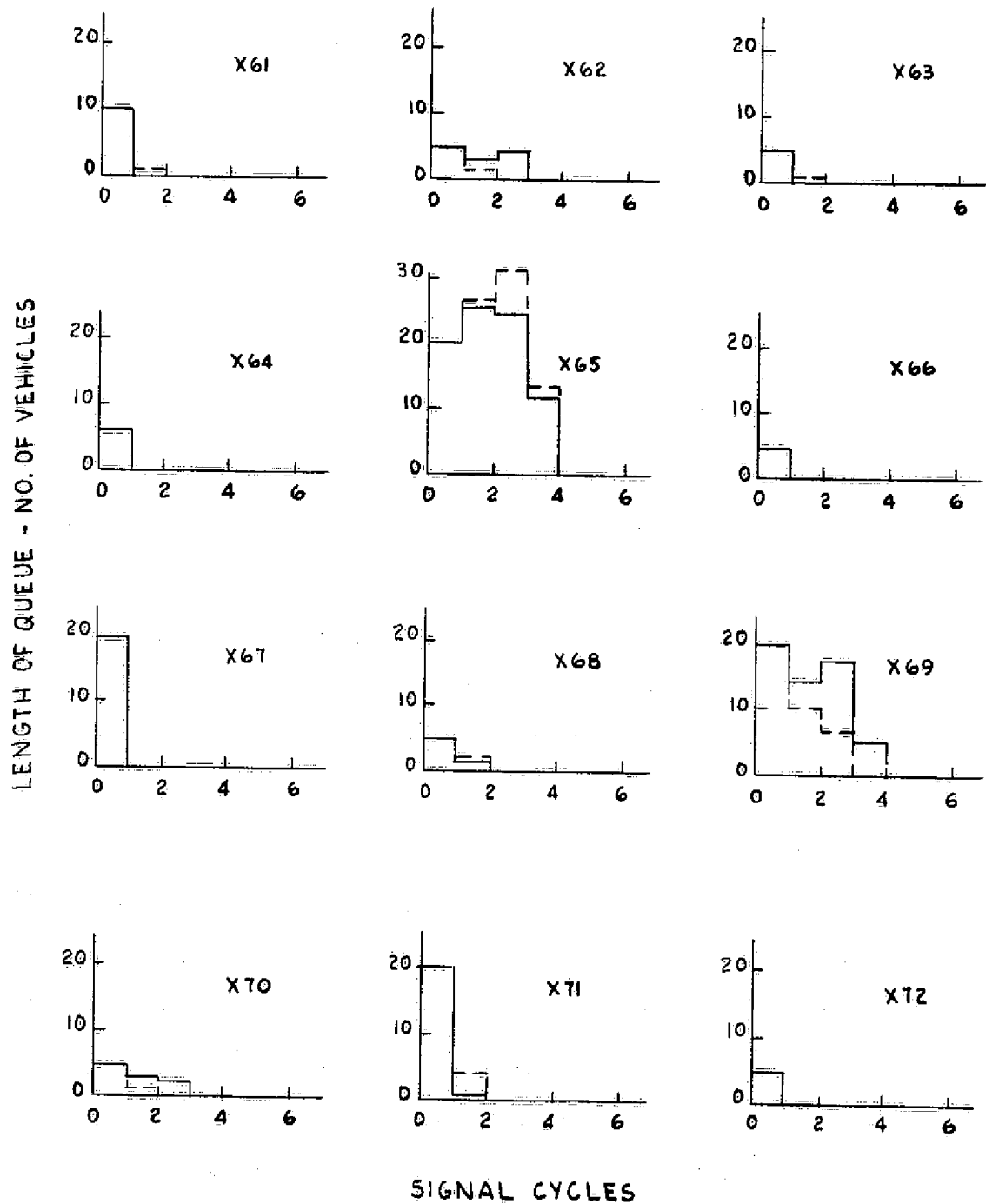
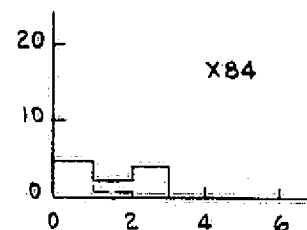
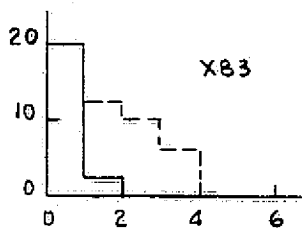
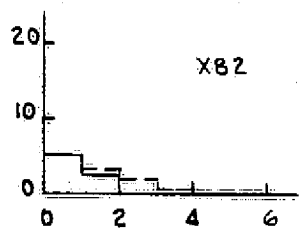
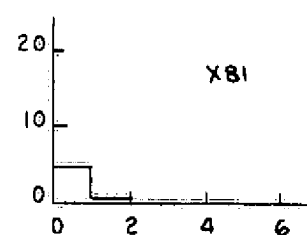
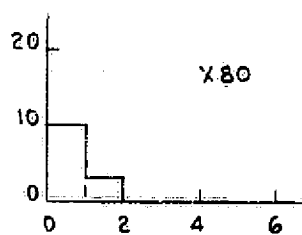
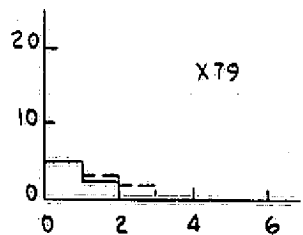
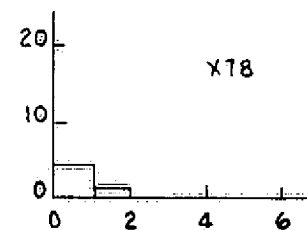
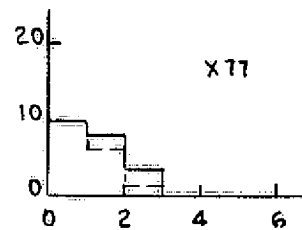
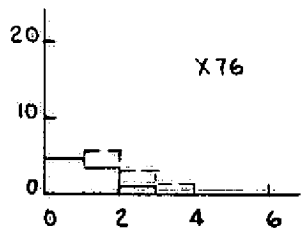
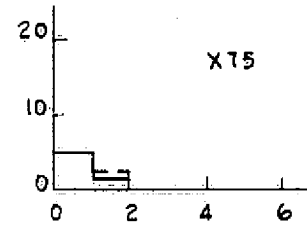
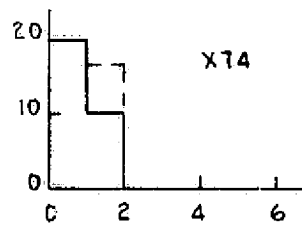
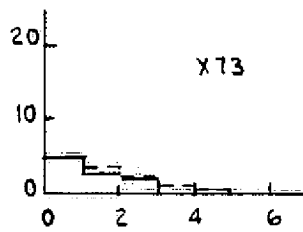


Figure 7-12(e). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 7-12(f). - Continued.

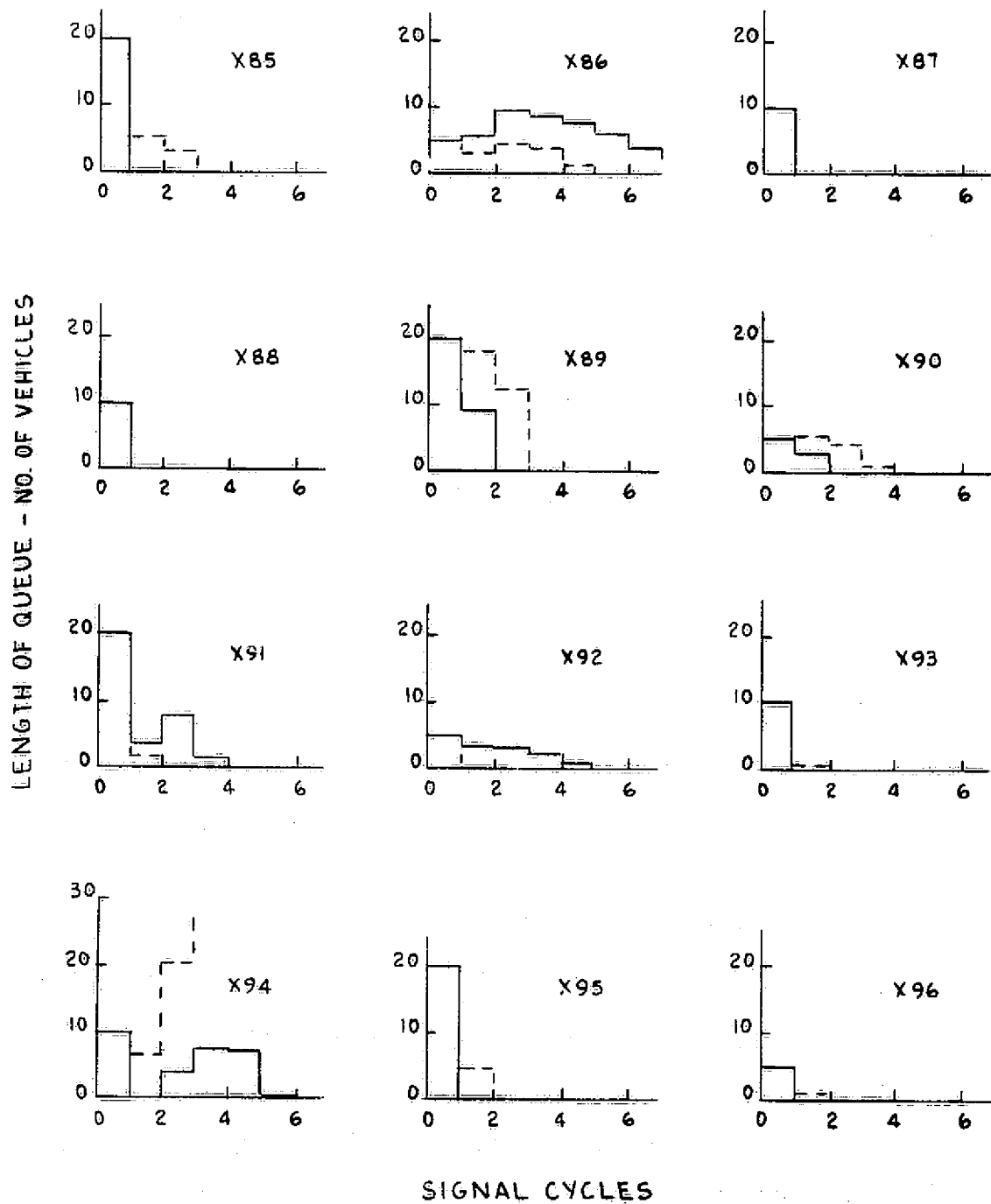


Figure 7-12(g). - Continued.

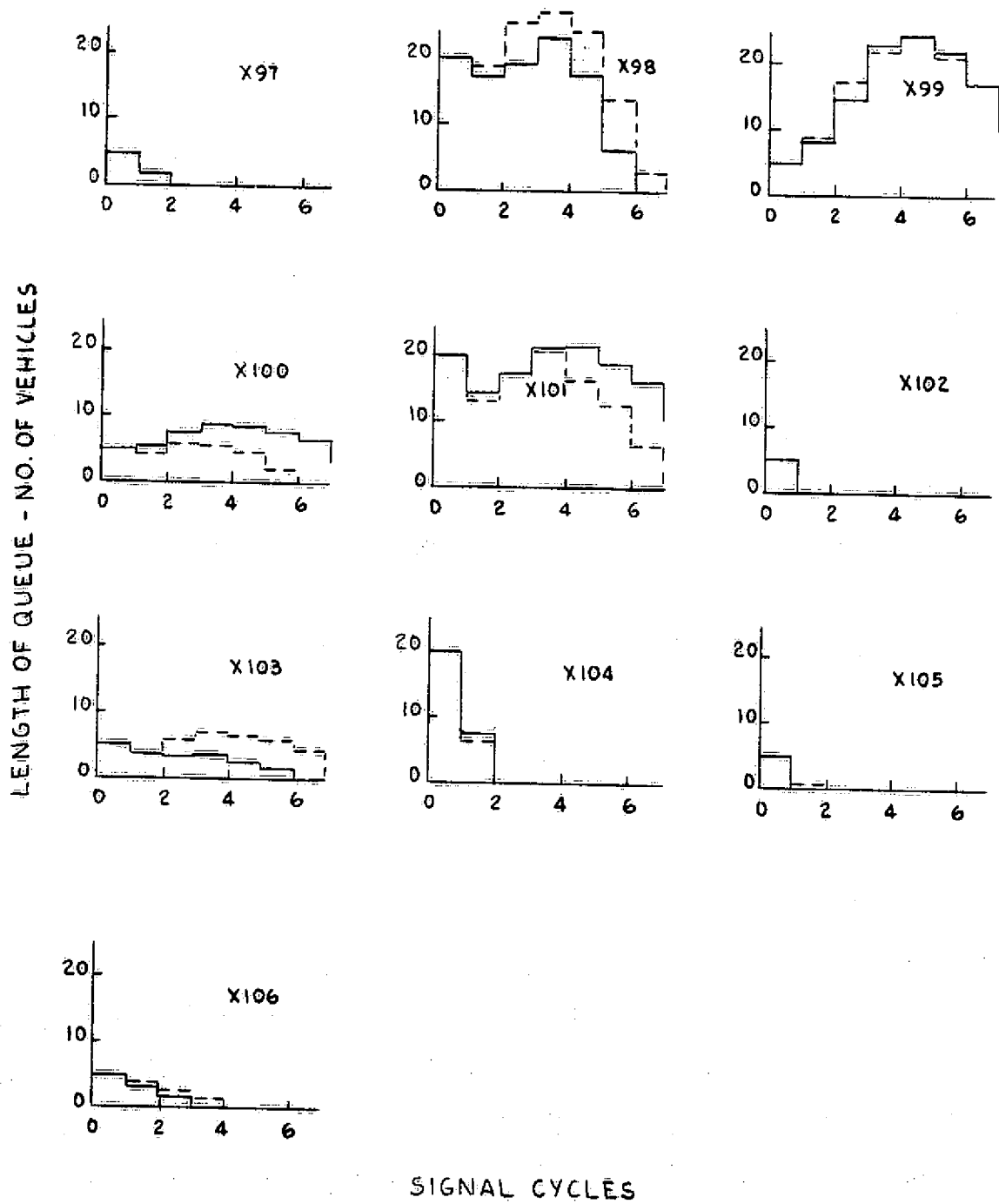


Figure 7-12(h). - Concluded.

tively reduce most queues within several signal cycles. Several queues such as Byrne-Heatherdowns RT (X35), Byrne-Winston-Glanzman LT (X48), Glanzman-Byrne RT (X52), and Schneider-Detroit LT (X94) increase to slightly higher levels than for the proposed control settings. Among critical queues are Airport-Byrne LT (X3), Byrne-Airport N-B (X7), and Heatherdowns LT (X39). These queues increase considerably and cause severe congestion.

The behavior of the vehicle queues for the 11-1 p.m. interval is given in figures 7-13 to 7-13(h). These results prove that effective control is possible with the proposed signal settings and control mode. The majority of the vehicle queues are eliminated and traffic build-up and congestion are not evident. Although several queues increase from their initial conditions, all of these queues will eventually dissipate. These critical queues are Byrne-Glanzman LT (X48), Glanzman-Byrne RT (X52), Byrne-Detroit RT (X65), Detroit-Glanzman LT (X86), and Detroit-Glendale RT (X99). Three queues represent right turn traffic, which most likely will proceed under suitable traffic conditions.

The results for the Toledo traffic signal settings are compared with the proposed settings in figures 7-13 to 7-13(h). Several queues tend to build up to link saturation and consequently congestion. But the majority of the queues are dissipated. The affected queues are Byrne-Airport N-B (X7), Byrne-Arlington LT (X14), Glendale-Byrne LT (X24), Byrne-Heatherdowns RT (X35), Heatherdowns-Byrne LT (X39), Byrne-Winston-Glanzman LT (X48), and Schneider-Detroit LT (X94). With the exception of queues X7 and X35, these queues represent left turn movements which are normally difficult to clear. The right turn queue (X35) will most likely dissipate since drivers will turn if passage is

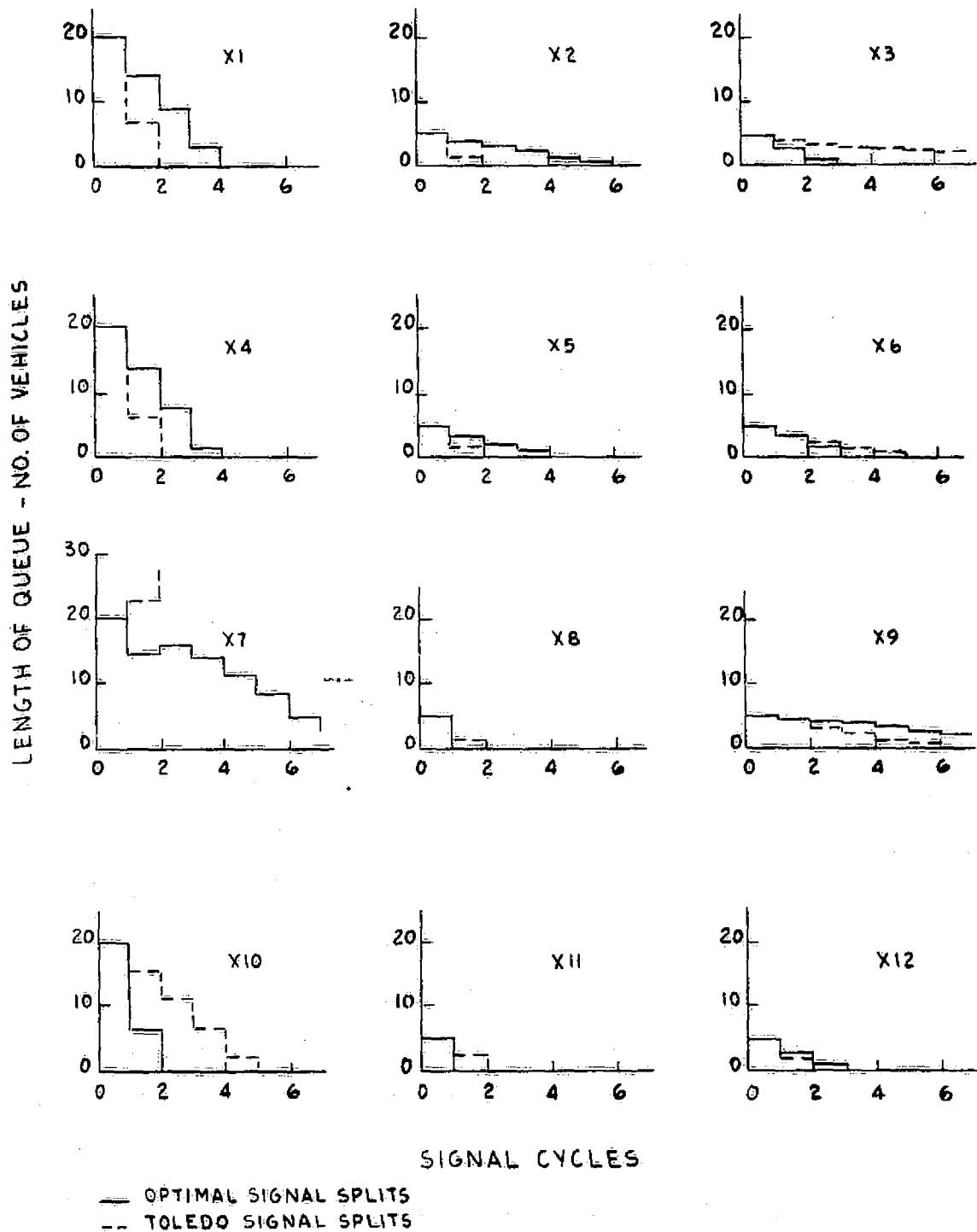


Figure 7-13. - Dissipation of vehicle queues, Section II, 11-1 p.m.



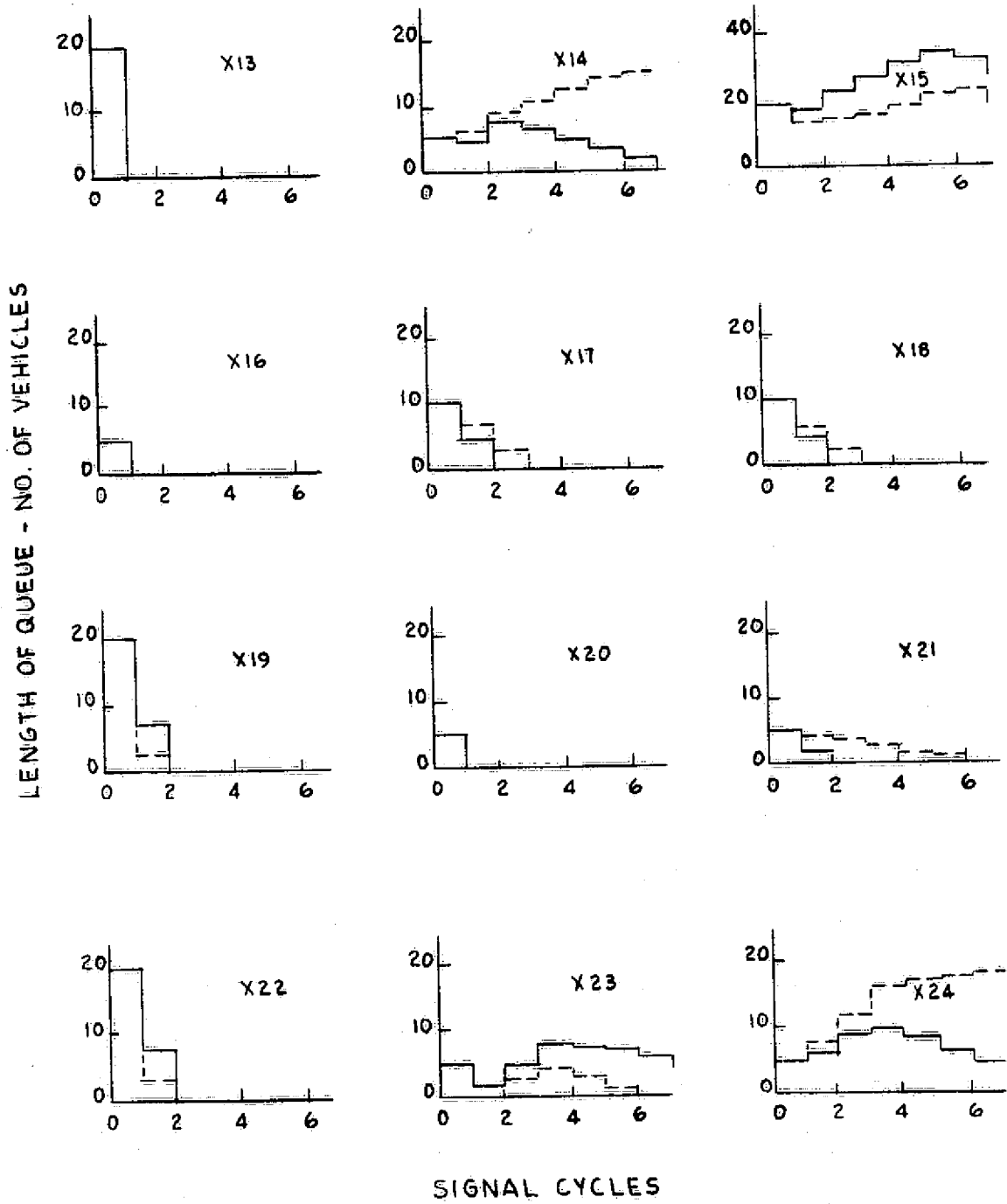
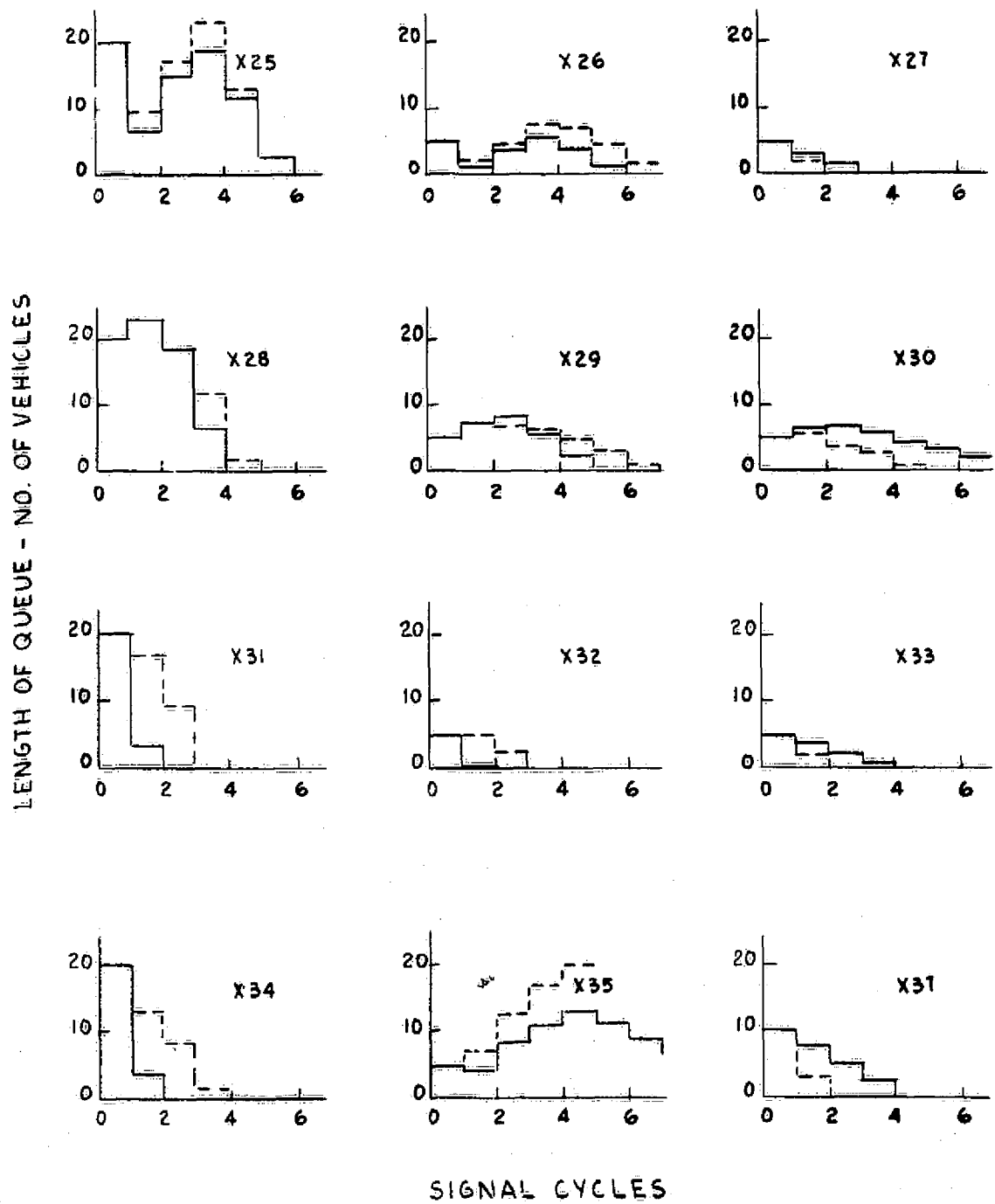


Figure 7-13(a). - Continued.



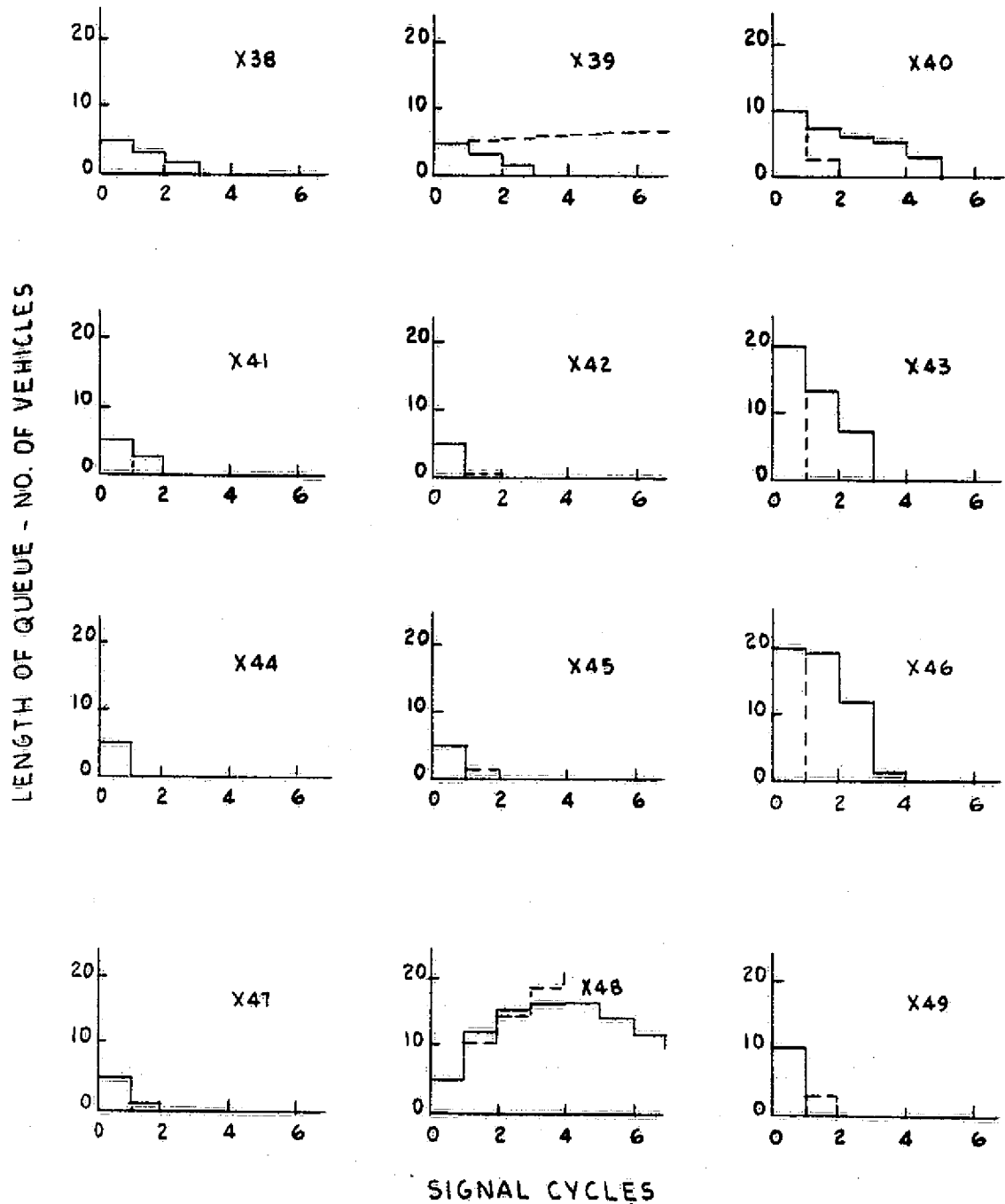
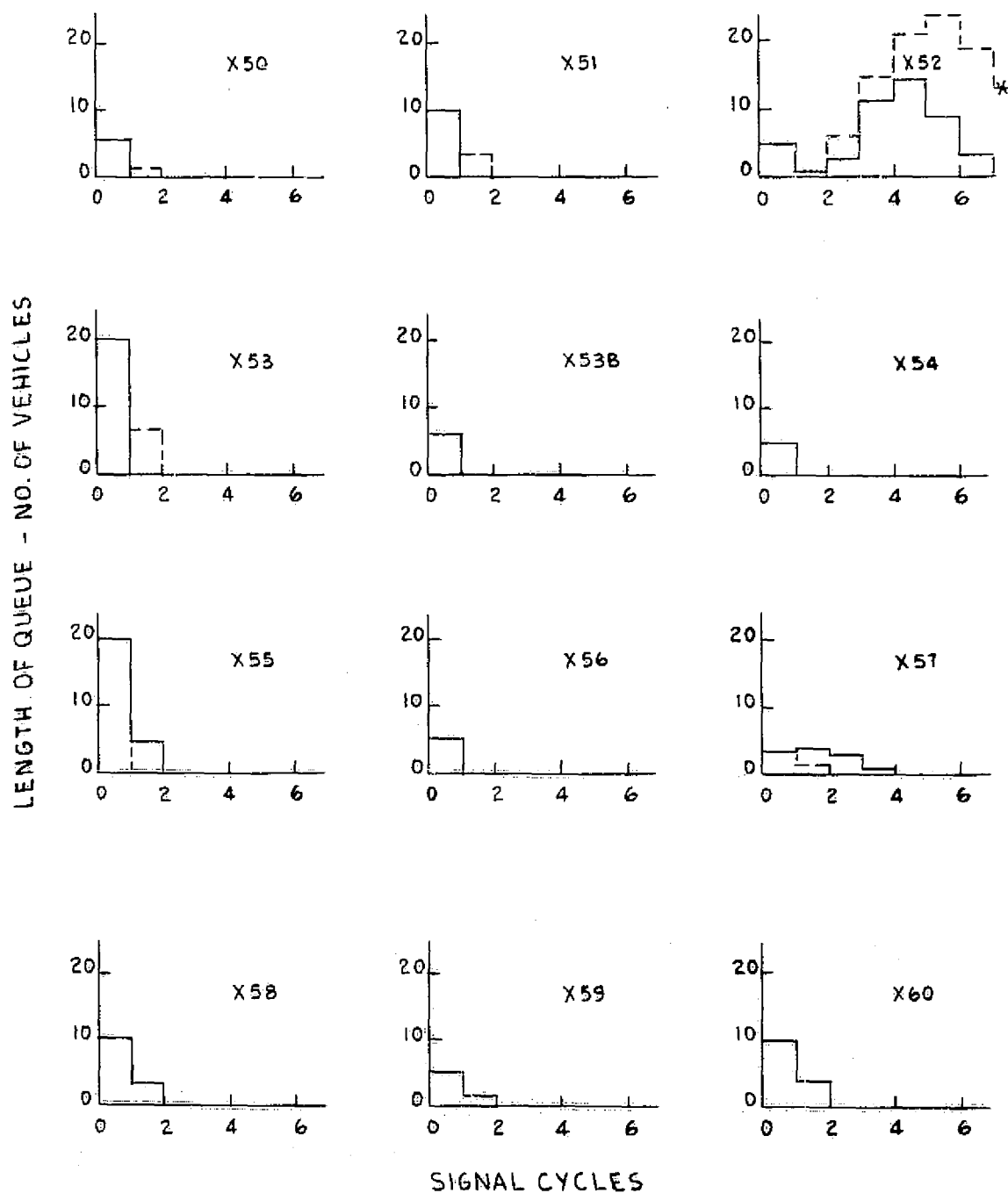


Figure 7-13(c). - Continued.



\* QUEUE REDUCES TO ZERO  
AFTER NINTH CYCLE

Figure 7-13(d). - Continued.

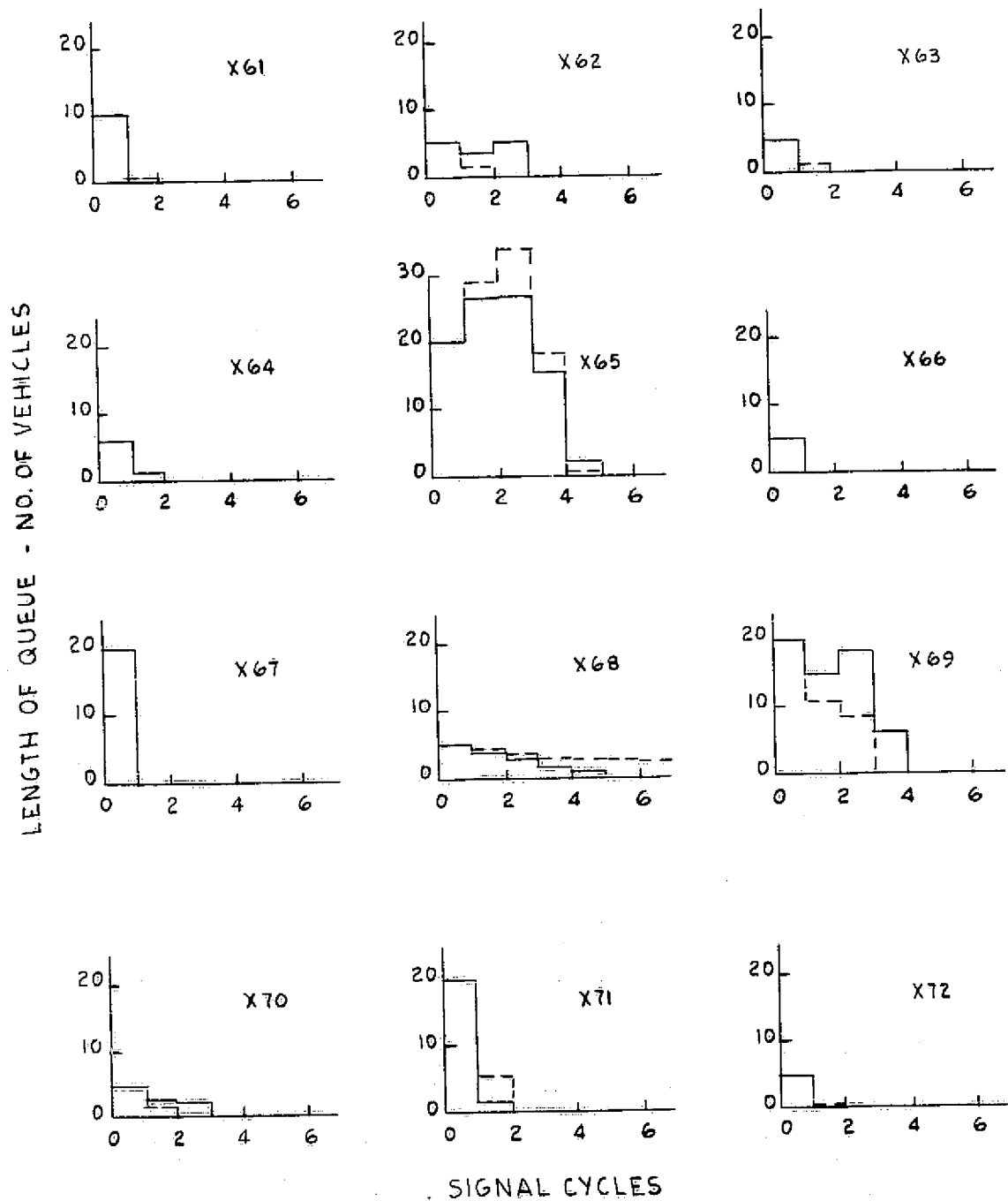


Figure 7-13(e). - Continued.

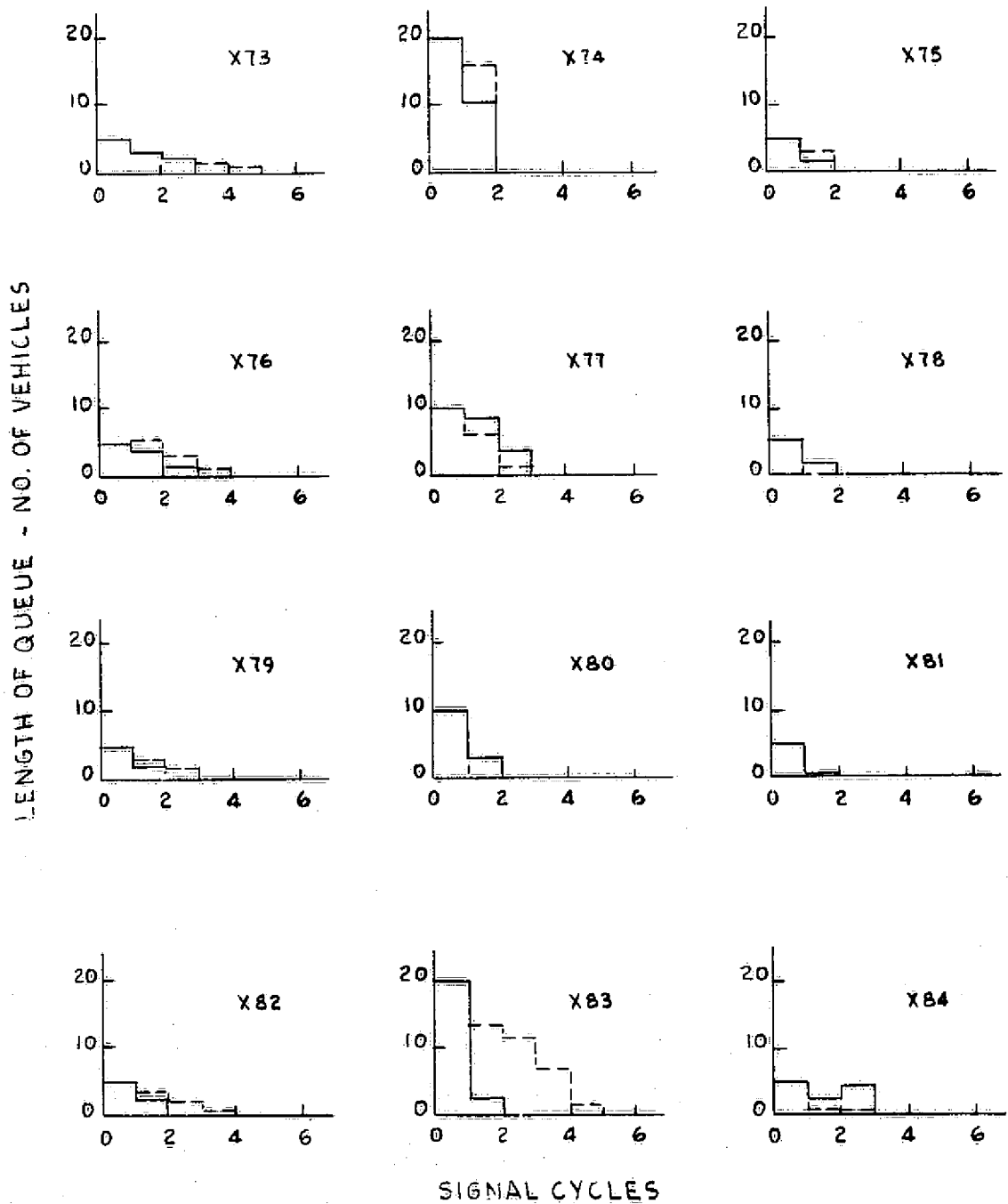


Figure 7-13(f). - Continued.

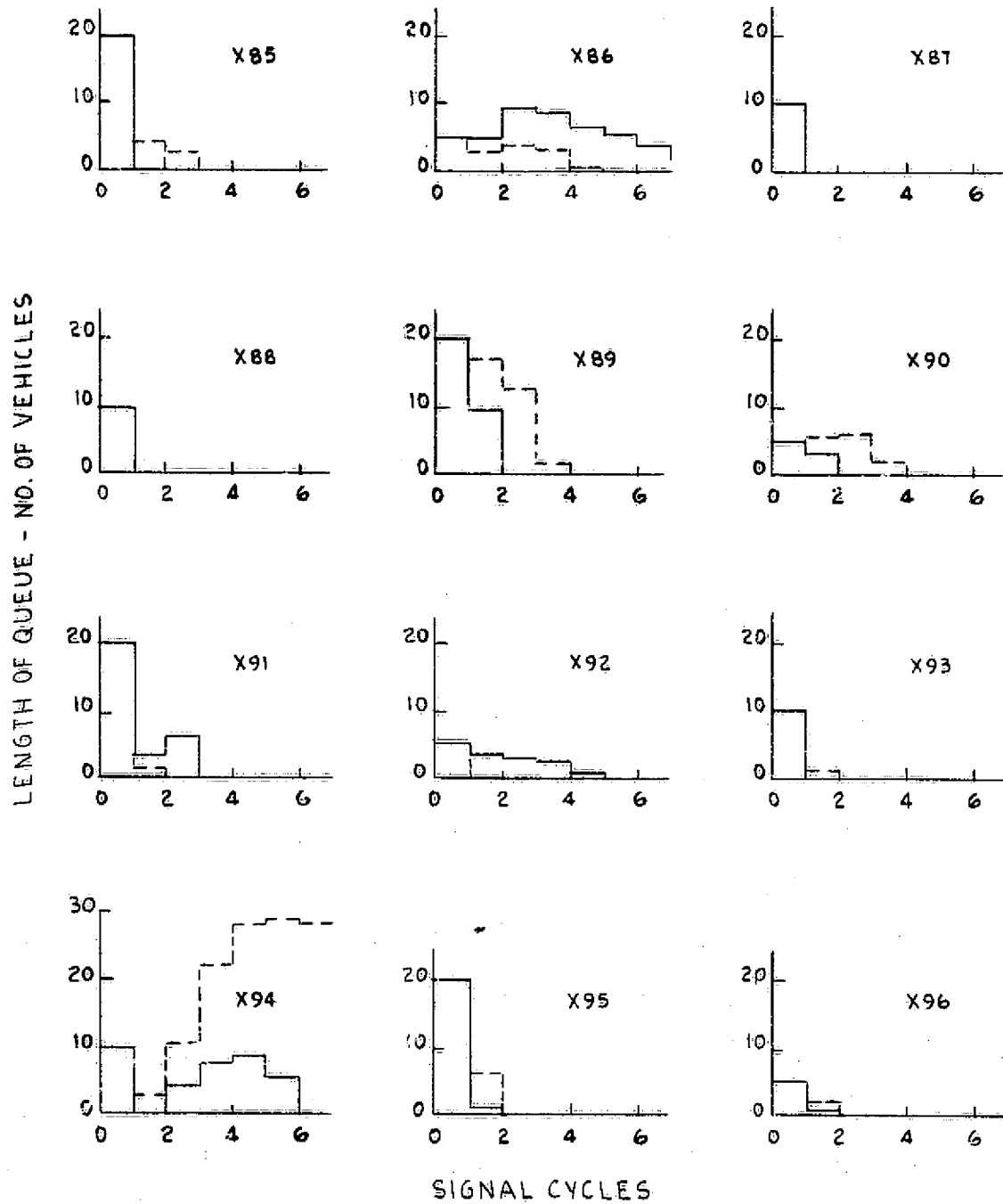


Figure 7-13(g). - Continued.

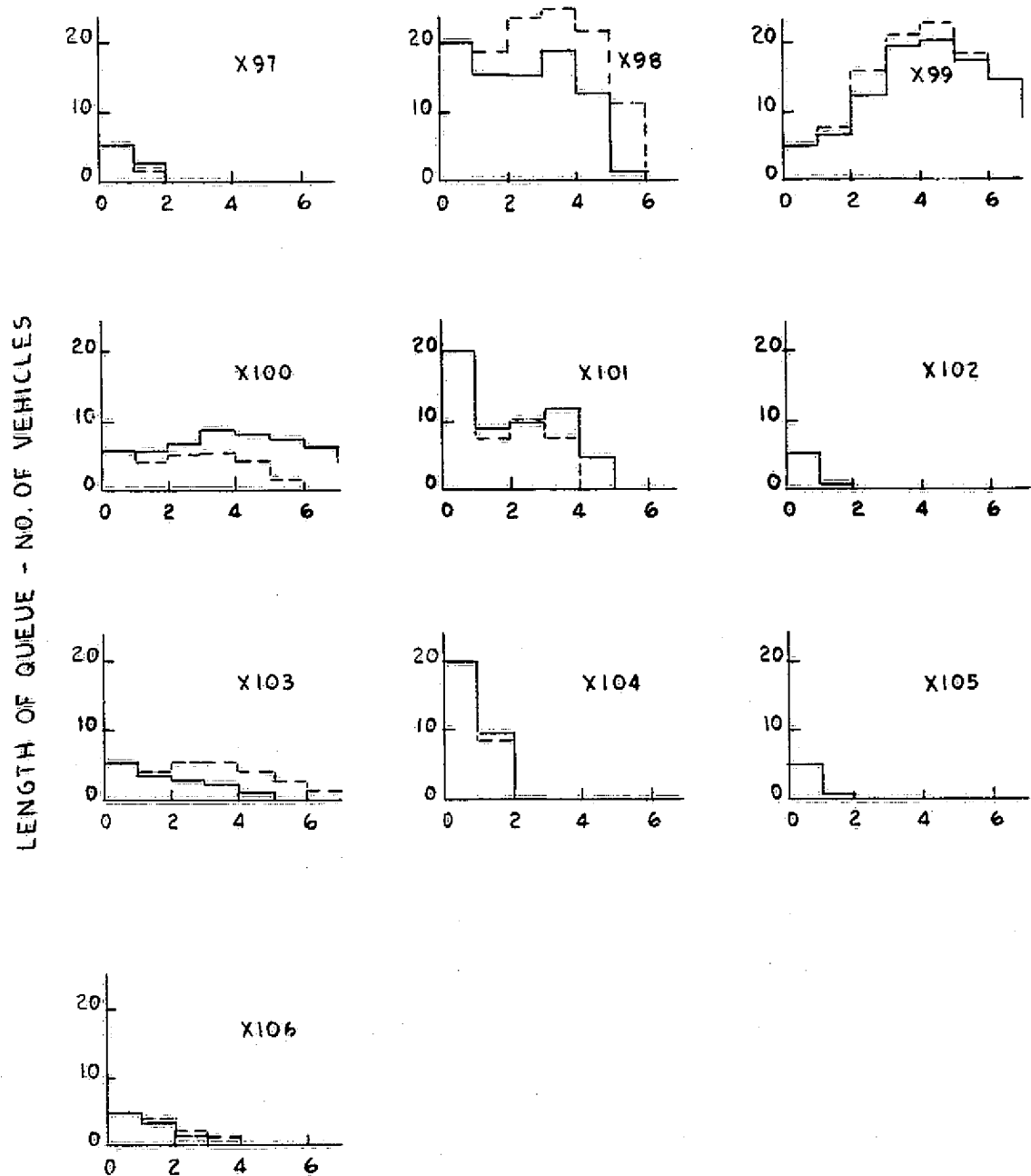


Figure 7-13(h). - Concluded.



not obstructed by main stream vehicles. For the model, the constant left turn green band was monitored to ensure that congestion is not encountered. This action was taken at the expense of a slower dissipation rate for the remaining queues.

The results for the 3-6 p.m. interval are illustrated in figures 7-14 to 7-14(h). With the proposed signal settings, the major portion of the queues are controllable and dissipate. However, due to high traffic flow, some difficulties could be encountered during this interval. Several queues such as Airport-Byrne RT (X2), Airport-Byrne LT (X3), and Glendale-Byrne RT (X23) either remain at a constant level or increase slightly. Drivers will be forced to wait for several cycles before proceeding through the intersection. A problem that appears consistent for all intervals is the Glanzman-Byrne RT (X52) queue. This queue, which is effectively reduced, still increases to high levels because of the delayed platoons. This queue receives most of the traffic flow discharged from the Detroit-Glanzman intersection (#C). About 93% of the arriving vehicles desire to make a right turn into Byrne. Also, the Detroit-Byrne S-B (X69) and Detroit-Glendale N-B (X98) queues increase to high levels (note change of scale on figures) but are effectively reduced without encountering congestion. By assigning a higher priority to the above queues (X52, X69, X98), the control variables are modified to increase the green band while penalizing noncritical queues. Even with these difficulties, the proposed control settings effectively control the traffic flow and eliminate congestion within the network.

The behavior of the vehicle queues for the Toledo system was compared to that under the proposed signal settings. It can be observed

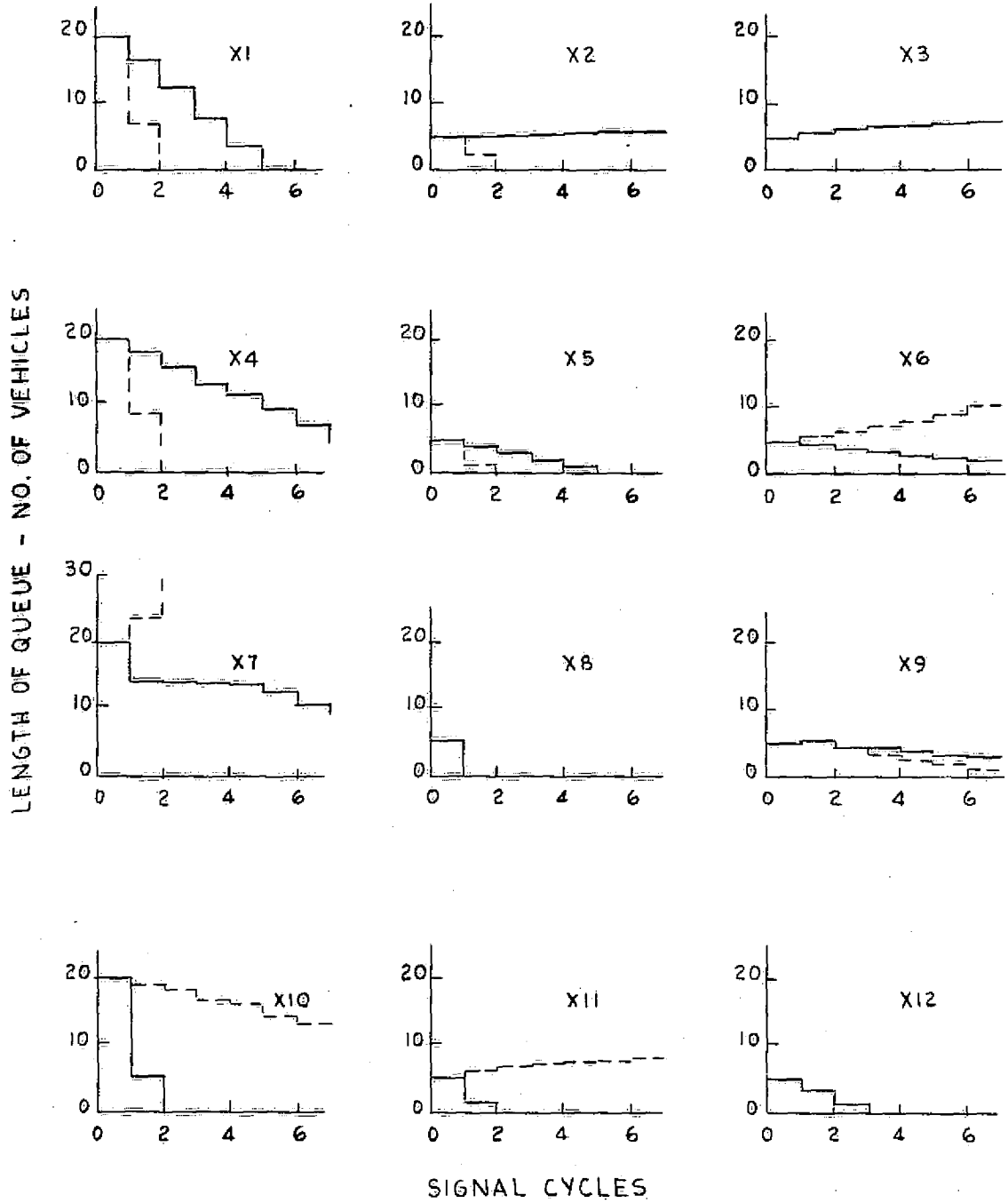


Figure 7-14. - Dissipation of vehicle queues, Section II, 3-6 p.m.

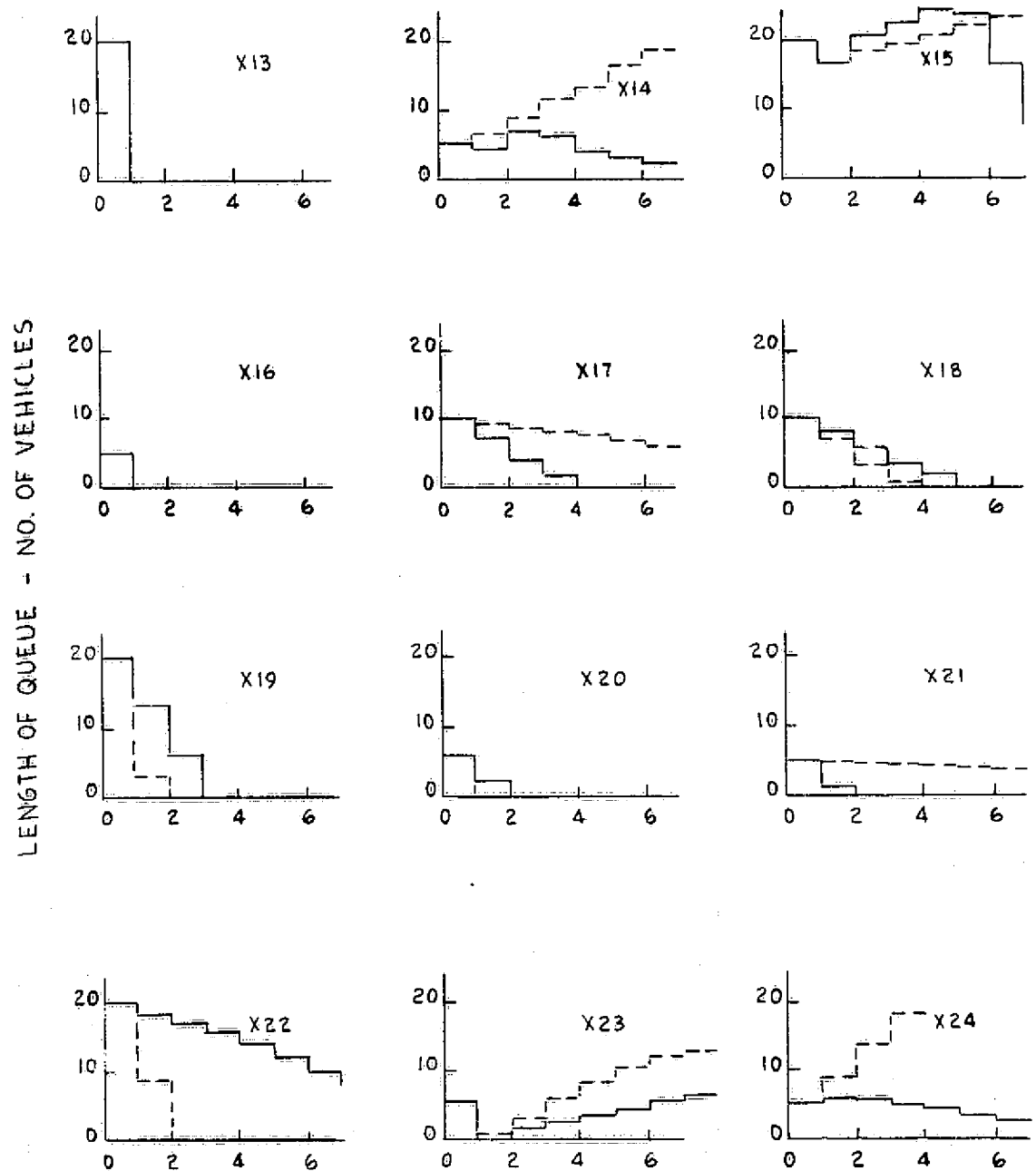


Figure 7-14(a). - Continued.

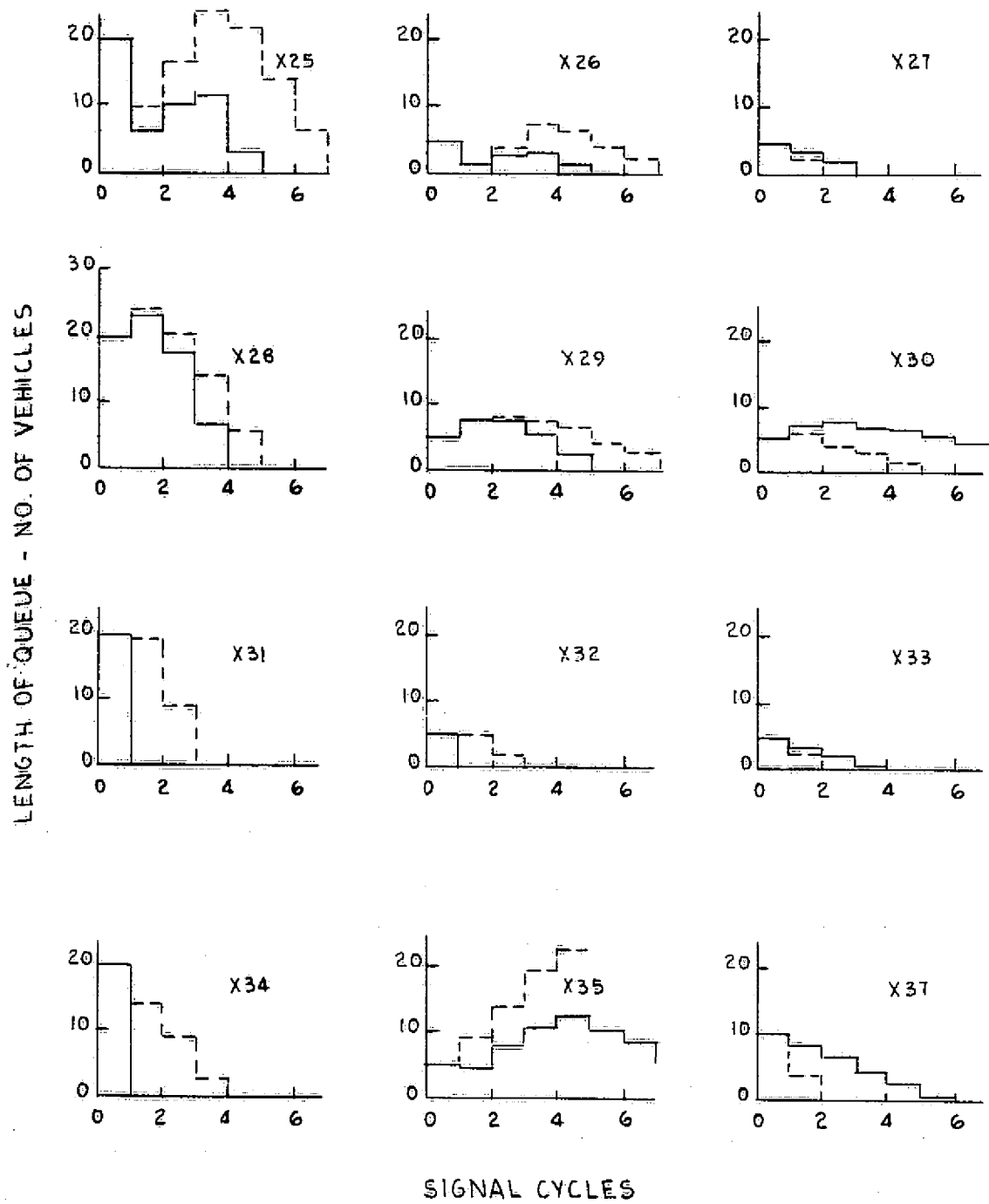


Figure 7-14(b). - Continued.

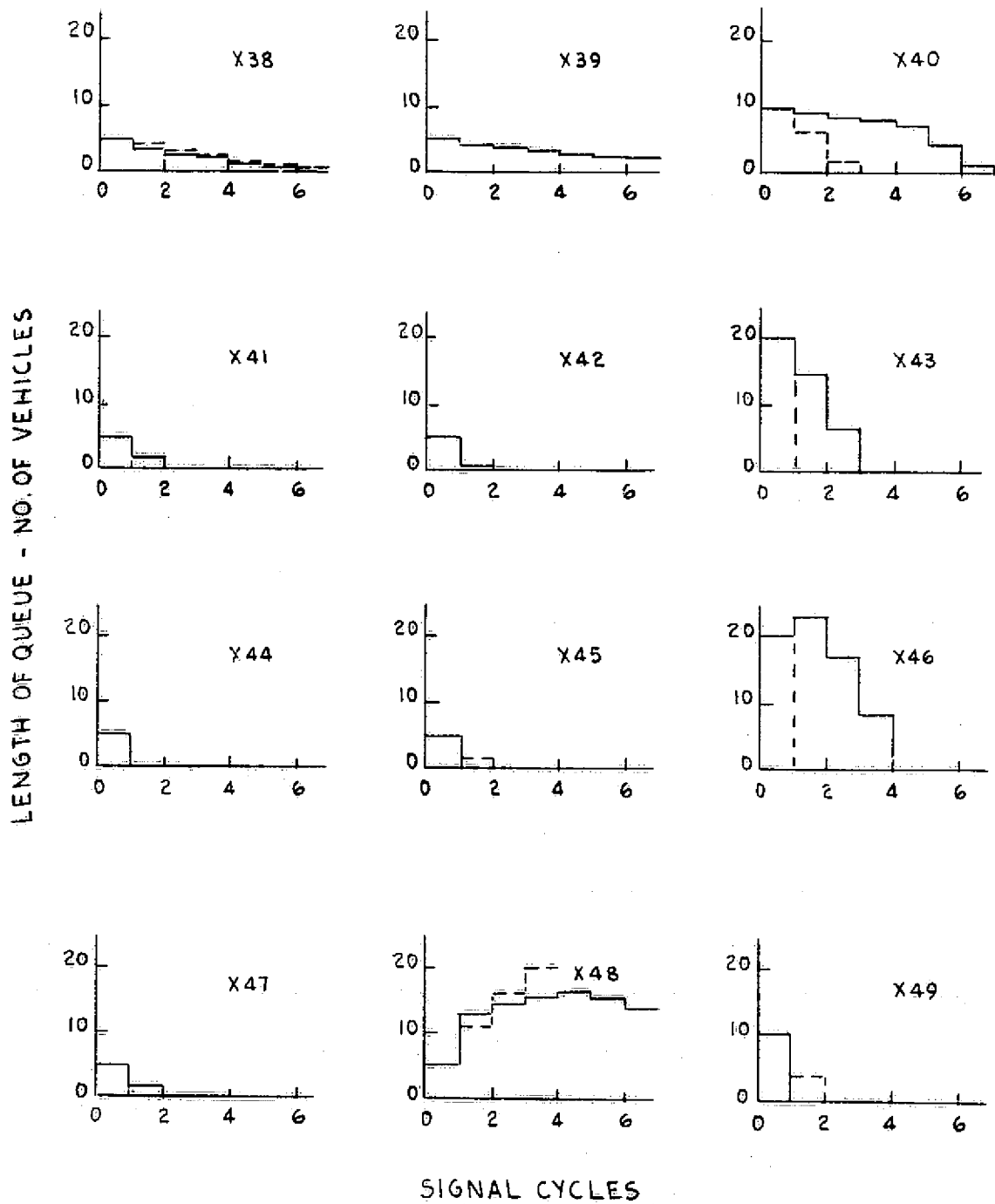
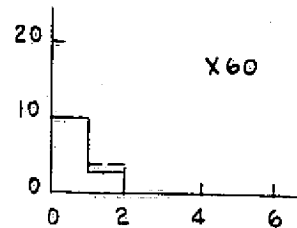
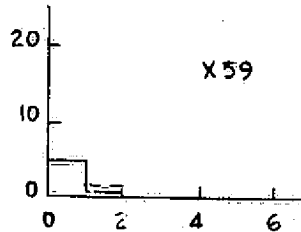
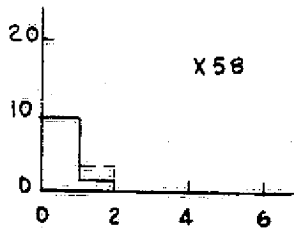
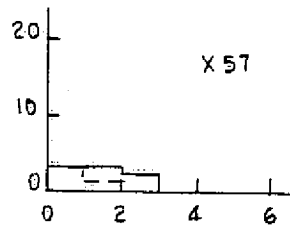
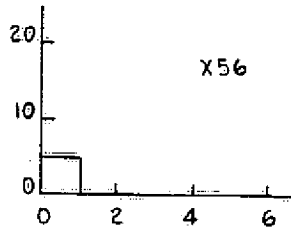
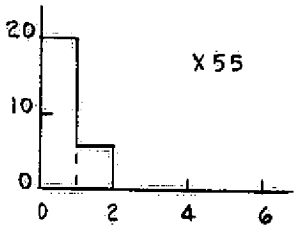
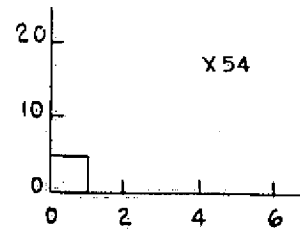
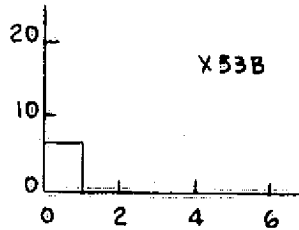
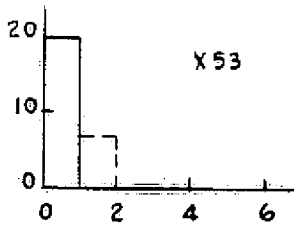
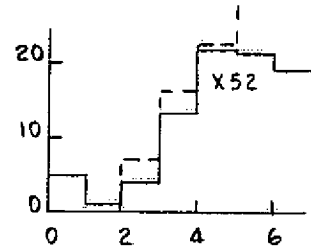
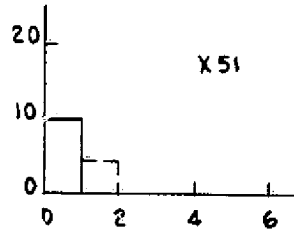
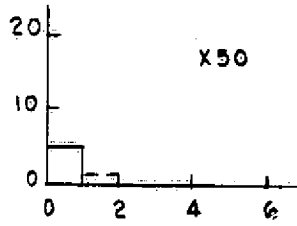


Figure 7-14(c). - Continued.

LENGTH OF QUEUE - NO. OF VEHICLES



SIGNAL CYCLES

Figure 7-14(d). - Continued.

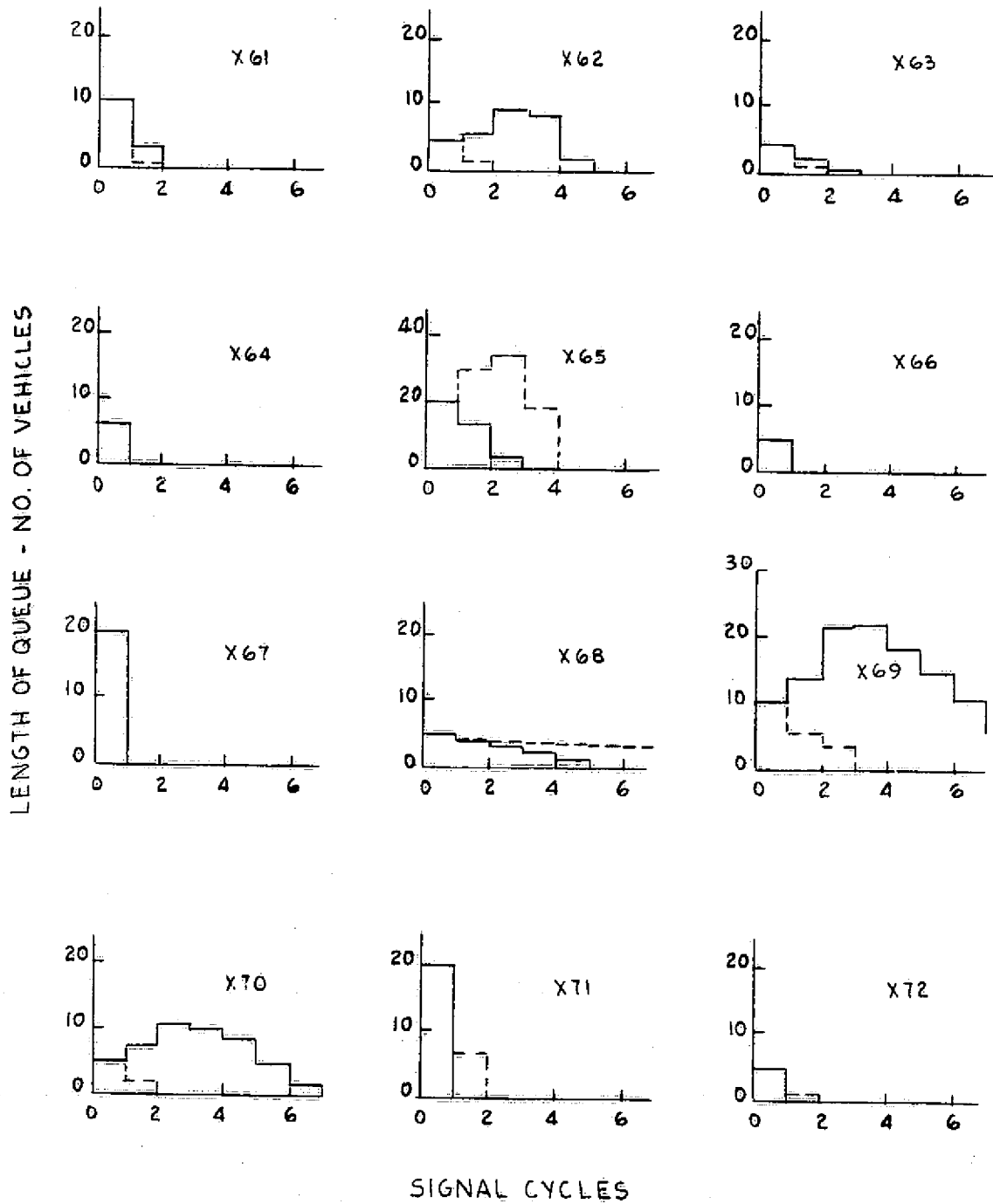


Figure 7-14(e). - Continued.

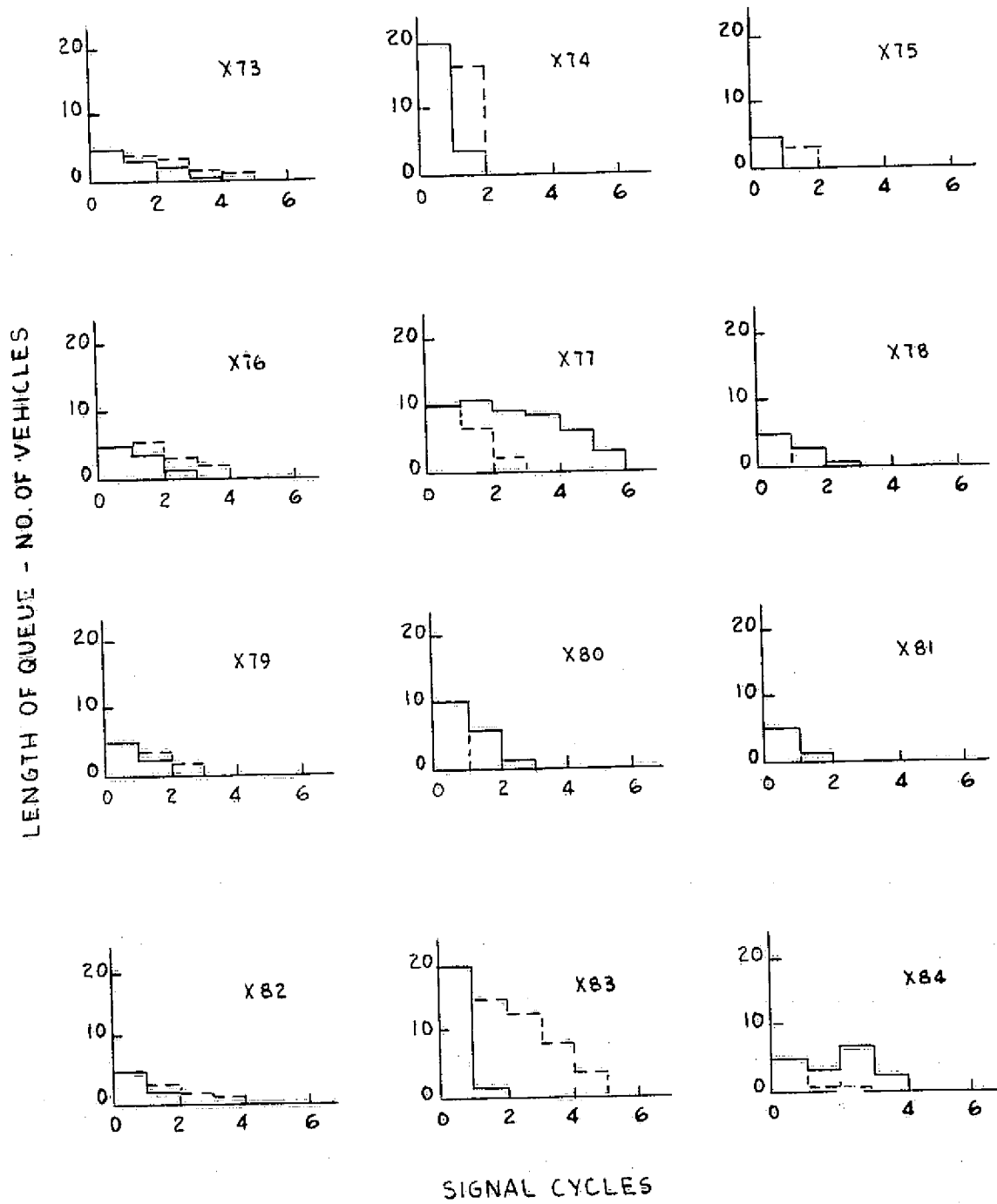


Figure 7-12(f). - Continued.



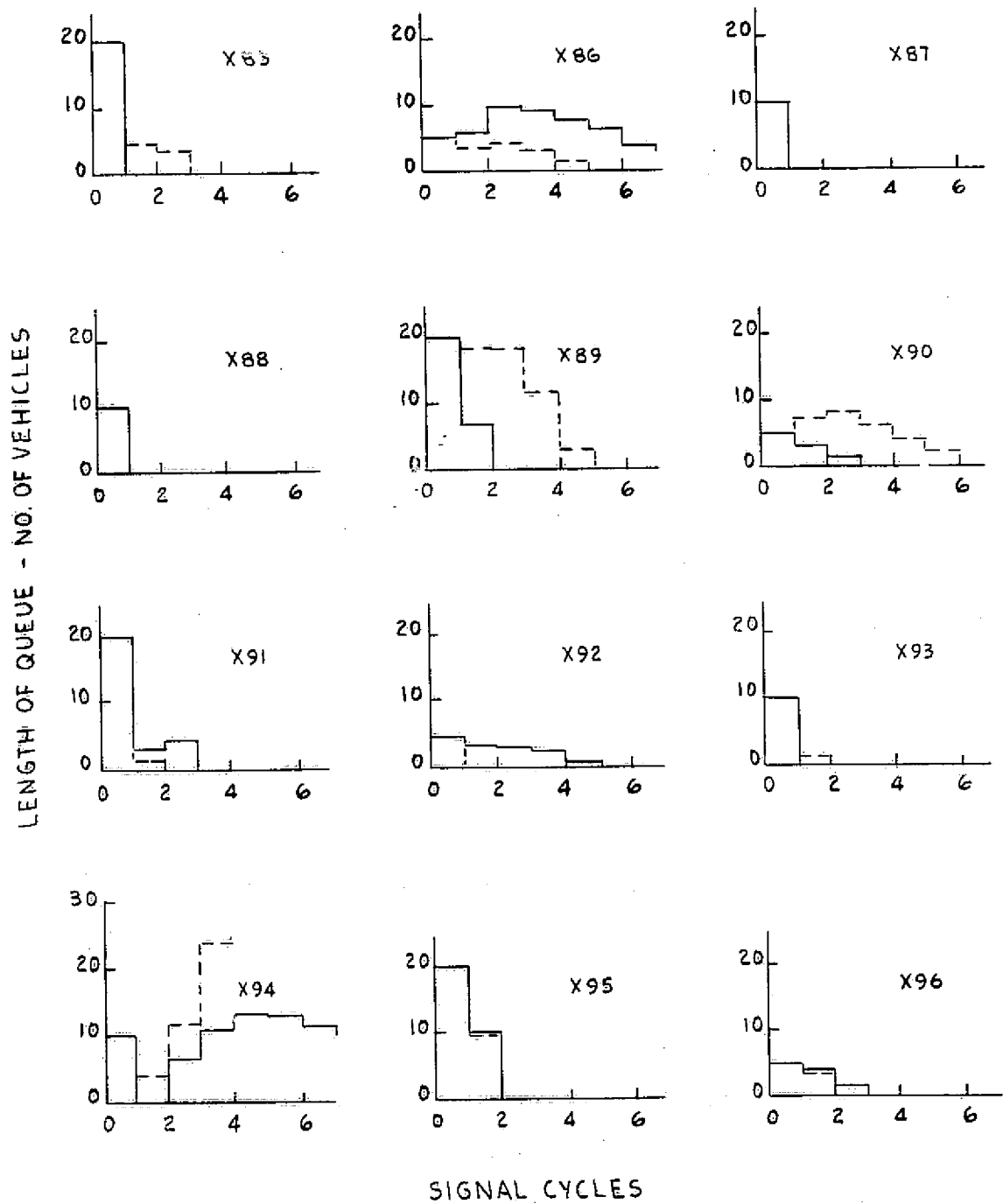


Figure 7-14(g). - Continued.

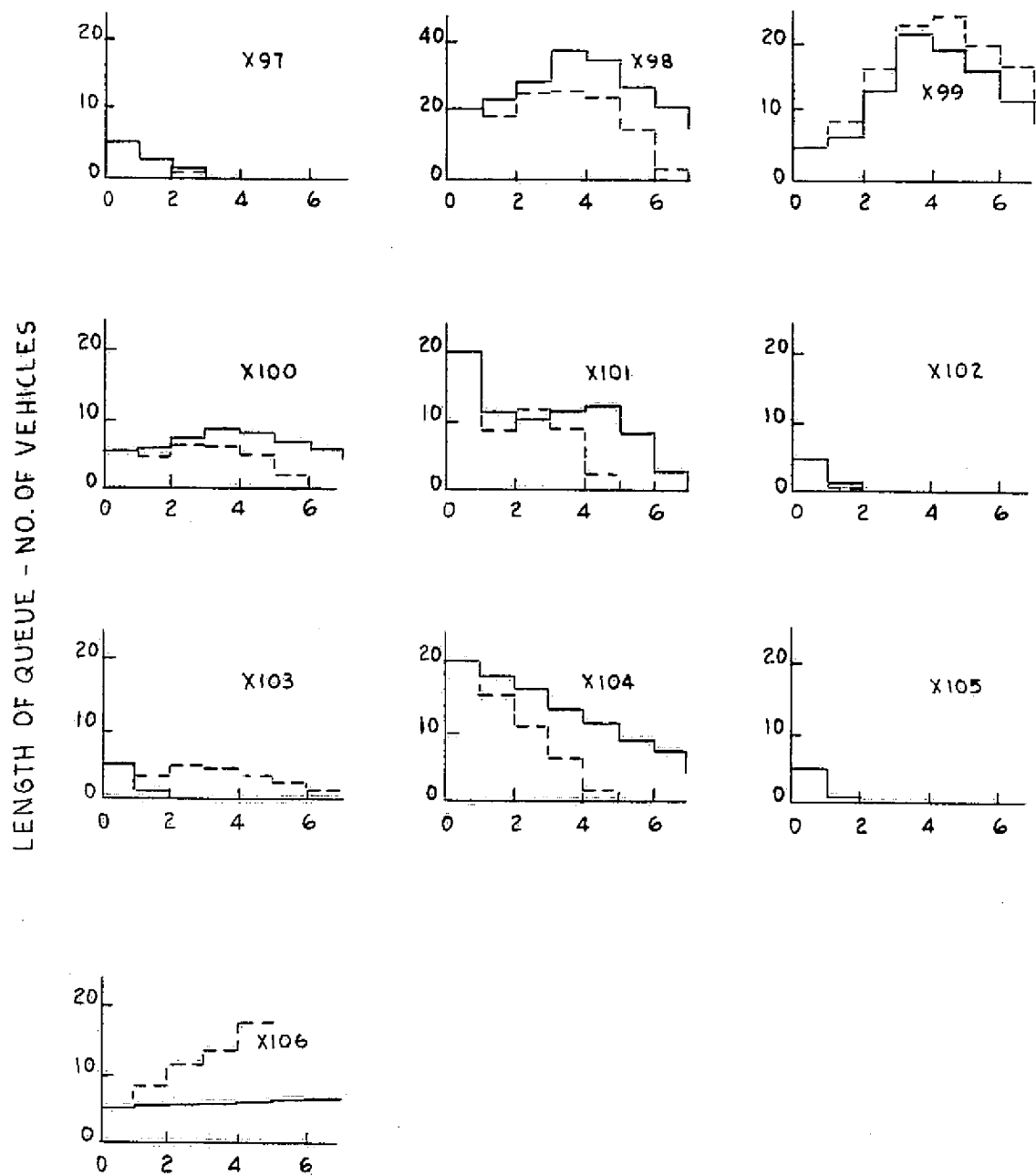


Figure 7-14(h). - Concluded.

from figures 7-14 to 7-14(h) that effective control can be established for about 90% of the queues, while the remainder either increase slowly or experience congestion. These difficulties exist for Byrne-Airport LT (X3, X6), Byrne-Airport N-B (X7), Byrne-Airport RT (X11), Byrne-Arlington LT (X14), Byrne-Arlington N-B (X15), Glendale-Byrne RT (X23), Glendale-Byrne LT (X24), Byrne-Heatherdowns RT (X35), Byrne-Winston-Glanzman LT (X48), and Glanzman-Byrne RT (X52). The majority of the above queues are either left or right turn movements. A similar traffic behavior for the queues is also experienced with the proposed signal settings. Due to the higher traffic flow during this time interval, the green band for the left turn queues was adjusted to the value at which the departure rate is above the arrival rate of the vehicles. As can be noted from table 7-2, the left turn green bands were increased for the 3-6 p.m. interval at intersections #452, #560, #A, thus allowing less time for other flow directions. To eliminate this problem, left turn movements should be eliminated at critical intersections during peak traffic periods. With this modification, a longer green band is available for other vehicle queues.

## CHAPTER VIII. CONCLUSIONS AND AREAS FOR FURTHER STUDY

### 8.1 Conclusions

The traffic theory presented in chapter IV was applied to a traffic network to compute the optimal traffic signal settings. The objective of the traffic control algorithm is to minimize the queue lengths and delay at each intersection. Due to the large number of state and control variables, it was necessary to divide the network into several smaller networks. This procedure can be justified since only boundary flows into the network are required and internal flows are generated from the discharged vehicles.

The models were formulated to conform to the traffic pattern of the specified networks. Optimal signal settings were obtained for main stream and right turn traffic. Left turn signal timing was maintained at a constant green band unless unusual traffic conditions required computed control settings. The term "unusual conditions" refers to critical queues that must be reduced rapidly and to large traffic flows to the left turn queues. The boundary flows are specified and constant during the selected time interval. The control procedure uses an off-line optimization technique.

The optimization was performed for a saturated two intersection model and two large traffic networks. The optimal traffic signal settings were obtained for three peak traffic conditions. An appropriate cost function considers the sum of the squares of the queue lengths at a steady state condition. State and control weighting are included to

ensure that critical queues are cleared effectively and control values are maintained within acceptable limits. Queue build-up can be eliminated by weighting the critical queues most heavily.

The results indicate that for the proposed signal settings, all queues dissipate within several signal cycles. Increases in queue lengths can be experienced due to the arrival of delayed vehicle platoons. Difficulties could be encountered for some turning queues, where drivers may be delayed for several signal cycles. Although state weighting was not considered for the two networks, this technique offers a method to clear critical queues while decreasing the dissipation rate of noncritical queues.

## 8.2 Areas of Further Study

Most of the basic principles of traffic control for heavy traffic flow have been demonstrated by applying the theory to actual traffic networks. However, several areas should be further investigated to improve the control procedure. The models were developed by using existing traffic data and service rates that may not be representative. Other suggestions may be useful as an addition to improve the operation of the traffic control system. The areas of further study include the following matters:

1. An off-line optimization procedure was used to derive the optimal signal settings. An optimal signal timing plan was derived for a specified time interval using average flow conditions. These signal settings must be maintained over the complete interval and do not vary according to changing traffic conditions. Presence sensors should be installed at boundary entrance points to monitor the actual flow to the network. In addition, sensors should be located at entrances along the

link to determine the actual number of vehicles that will arrive at an intersection. Using actual flow measurements, the signal splits can be updated at regular intervals.

2. The traffic models were developed for a common signal cycle. Whenever long vehicle queues are apparent or several flow directions must be accommodated, it may be advisable to increase the cycle lengths at selected intersections. This procedure will allow a larger green band for all traffic flow directions.

3. The platoon travel time between intersections was obtained from actual measurements recorded by the traffic engineer. These magnitudes can vary depending on weather and roadway conditions, and the speed of the leading vehicles in the platoon. The effects of varying travel time must be analyzed to establish the sensitivity of the traffic signal settings.

4. The optimization procedure for sections I and II uses an equally weighted performance index. The results of the behavior of the vehicle queues show that the dissipation rate of many queues is low, whereas some queues clear very rapidly. By using heavier weighting (greater cost) for selected queues, the critical queues can be reduced more effectively. By penalizing the critical queues most heavily, these queues can be given a larger green through band.

5. The service rates of the queues were chosen according to general traffic theory. These values were reduced by about 11% and represent the maximum value that can be accommodated by the roadway under ideal conditions. The service rates may vary according to weather and roadway conditions. More representative service rates should be obtained and applied to the traffic models for abnormal conditions.

6. The traffic models do not include the effects of accidents, stalled and parked vehicles. These conditions will reduce the service rate at the affected intersection, thereby causing a slower dissipation rate of some queues and possible congestion. Incident detection should be considered so that emergency aid can be dispatched to clear the roadway.

7. Lock-up or failure of the traffic signal to allow a green through band in a flow direction will cause other vehicle queues to increase to congestion levels. Sensing devices to detect these types of failures should be installed.

8. Most drivers generally use the same daily route and should not be subjected to long queues and delays. Studies should be conducted to determine the queue length that must be attained before drivers are induced to detour to other routes. The use of information devices to warn drivers of a large queue may be useful.

## APPENDIX A. DEFINITIONS OF TRAFFIC TERMINOLOGY

### Definition A-1

Flow ( $q$ ) is the number of vehicles entering a link in a specified unit of time (number of vehicles/hr)

### Definition A-2

Density ( $\rho$ ) is the number of vehicles within a link for a specified time interval (number of vehicles/mile)

### Definition A-3

Space mean speed ( $\mu$ ) is the average velocity of the vehicles within a link at a specified time (miles/hr)

### Definition A-4

Link is a road interval between two intersections.

### Definition A-5

Signal cycle is the time for a complete set of traffic phases at an intersection. A traffic phase is part of a cycle allocated to any traffic movement receiving the right of way. The number of phases required for an intersection varies with the directions of traffic flow.

### Definition A-6

Signal split is the ratio of the traffic phases. For an intersection with two phases (phases A and B), split is defined as the ratio of phase A to phase B.



## Definition A-7

Offset is the time duration between the initiation of the green band at the downstream intersection relative to the upstream intersection.

## Definition A-8

Delay is the waiting time incurred at the traffic signal downstream of the link.

## Definition A-9

Occupancy is the percent of time that the presence detector is activated. From this time interval and an estimate of the vehicle length, the speed can be computed.

APPENDIX B - LISTING OF COMPUTER PROGRAMS - TWO INTERSECTION MODEL

```

C
C *** CALL PROGRAM FOR OPTIMIZATION OF BYRNE-DOER-SECOR INTERSECTIONS
C
C   THE FOLLOWING PARAMETERS ARE USED IN THE CALL PROGRAM
C
C   TSPC  - A FUNCTION SUBPROGRAM (TRAFFIC MODEL)
C   EPS   - CONVERGENCE CRITERION
C   N     - LENGTH OF THE VECTOR ARRAY U (INPUT)
C   U     - A VECTOR ARRAY OF LENGTH N. FOR INPUT, U IS AN INITIAL GUESS
C           FOR THE MINIMUM. FOR OUTPUT U IS THE COMPUTED MINIMUM POINT
C   FMIN  - TSPC(U) - FUNCTION TSPC EVALUATED AT U (OUTPUT)
C   ITMAX - FOR INPUT IS THE MAXIMUM ALLOWABLE NUMBER OF ITERATIONS
C           PER ROOT AND FOR OUTPUT IS THE NUMBER OF ITERATIONS USED
C   WA    - A VECTOR WORK AREA OF LENGTH N*(N+4)
C   IER   - ERROR PARAMETER (OUTPUT)
C
C           TERMINAL ERROR = 128+N
C           N = 1 NO FINITE MINIMUM OBTAINED
C           N = 2 TSPC IS LEVEL ALONG A LINE THROUGH U
C           N = 4 FAILURE TO CONVERGE IN ITMAX ITERATIONS
C           N = 8 GRADIENT 'LARGE' AT CALCULATED MINIMUM
C
C   IMPLICIT REAL*8 (A-H,O-Z)
C   EXTERNAL TSPC
C   DIMENSION U(4),WA(32)
C   N=4
C   EPS=.001
C   ITMAX=100
C   U(1)=.0224
C   U(2)=.0555
C   U(3)=.0538
C   U(4)=.0433
C   CALL ZXPOWL (TSPC,EPS,N,U,FMIN,ITMAX,WA,IER)
C   WRITE (6,100) FMIN,ITMAX
100  FORMAT (2X, 'FMIN= ',G12.5, 'ITMAX= ',I3)
C   STOP
C   END

```

Figure B-1.

C \*\*\* FUNCTION FOR OPTIMIZATION - BYRNE-DORR-SECOR INTERSECTIONS

C

```

DOUBLE PRECISION FUNCTION TSPC(U)
DOUBLE PRECISION U
DIMENSION U(4)
DIMENSION X59(92),X60(92),X61(92),X62(92),X63(92),X64(92),
2X65(92),X66(92),X67(92),X68(92),X69(92),X70(92),X71(92),X72(92), -
3X73(92),X74(92),W59(92),W60(92),W61(92),W62(92),W63(92),W64(92), -
4W65(92),W66(92),W67(92),W68(92),W69(92),W70(92),W71(92),W72(92), -
5W73(92),W74(92),D59(92),D60(92),D61(92),D62(92),D63(92),D64(92), -
6D65(92),D66(92),D67(92),D68(92),D69(92),D70(92),D71(92),D72(92), -
7D73(92),D74(92),Q59(92),Q60(92),Q61(92),Q62(92),Q63(92),Q64(92), -
8Q65(92),Q66(92),Q67(92),Q68(92),Q69(92),Q70(92),Q71(92),Q72(92), -
9Q73(92),Q74(92),U7(92),U7A(92),U8(92),U8A(92)
DATA X59(1),X60(1),X61(1),X62(1),X63(1)/10.,10.,20.,5.,20./
DATA X64(1),X65(1),X66(1),X67(1),X68(1)/5.,20.,5.,5.,20./
DATA X69(1),X70(1),X71(1),X72(1),X73(1),X74(1)/5.,10.,5.,5.,10.,5./
DATA S59,S60,S61,S62,S63,S64,S65,S66/40.,40.,80.,25.,80.,25.,80.,25./
DATA S67,S68,S69,S70,S71,S72,S73,S74/25.,80.,25.,40.,25.,25.,40.,25./
DATA R63,R64,R65,R66,R67,R71/1.,5.,1.,1.,50.,1./
DATA XM63,XM64,XM65,XM66,XM67/40.,40.,40.,40.,40./
DATA R7,R7A,R8,R8A/0.,0.,0.,0./
TFR = 10.
Q59(1) = 9.78/TFR
Q60(1) = 4.66/TFR
Q61(1) = 10.3/TFR
Q62(1) = 3.43/TFR
Q630 = 10.48/TFR
Q640 = 10.71/TFR
Q650 = 8.34/TFR
Q660 = .24/TFR
Q670 = 11.79/TFR
Q68(1) = 8.19/TFR
Q69(1) = 3.18/TFR
Q70(1) = .675/TFR
Q71(1) = 12.8/TFR
Q72(1) = 4.1/TFR
Q73(1) = 1.84/TFR
Q74(1) = .25/TFR
ALP7 = 0.90/TFR
ALP8 = 0.90/TFR
DEL8 = 0.20/TFR
U7(1) = U(1)
U7A(1) = U(2)
U8(1) = U(3)
U8A(1) = U(4)
DO 100 K=1,91
U7(K) = U7(1)
U7A(K) = U7A(1)
U8(K) = U8(1)
U8A(K) = U8A(1)
Q59(K) = Q59(1)
Q60(K) = Q60(1)
Q61(K) = Q61(1)

```

Figure B-2.

```

Q62(K) = Q62(1)
Q68(K) = Q68(1)
Q69(K) = Q69(1)
Q70(K) = Q70(1)
Q71(K) = Q71(1)
Q72(K) = Q72(1)
Q73(K) = Q73(1)
Q74(K) = Q74(1)
100 CONTINUE
DO 200 K=1,91
  L=K+1
  MK=K-1
  KN=K-3
C
C *** INTERSECTION 478 BYRNE-DORR
C
D59(K) = S59*U7(K)
W59(K) = X59(K) + Q59(K)
IF (W59(K) .GT. D59(K)) GO TO 126
IF (W59(K) .LT. D59(K)) D59(K) = W59(K)
126 IF (MK .LT. 1) W65(MK)=X65(1)+Q650
IF (MK .LT. 1) W66(MK)=X66(1)+Q660
IF (MK .LT. 1) W67(MK)=X67(1)+Q670
IF (W65(MK) .GE. XM65) D59(K)=0.
IF (W66(MK) .GE. XM66) D59(K)=0.
IF (W67(MK) .GE. XM67) D59(K)=0.
X59(L) = X59(K) - D59(K) + Q59(K)
D60(K) = S60*U7(K)
W60(K) = X60(K) + Q60(K)
IF (W60(K) .GT. D60(K)) GO TO 128
IF (W60(K) .LT. D60(K)) D60(K) = W60(K)
128 X60(L) = X60(K) - D60(K) + Q60(K)
D61(K) = S61*(ALP7 - U7(K) - U7A(K))
W61(K) = X61(K) + Q61(K)
IF (W61(K) .GT. D61(K)) GO TO 130
IF (W61(K) .LT. D61(K)) D61(K) = W61(K)
130 IF (MK .LT. 1) W65(MK)=X65(1)+Q650
IF (MK .LT. 1) W66(MK)=X66(1)+Q660
IF (MK .LT. 1) W67(MK)=X67(1)+Q670
IF (W65(MK) .GE. XM65) D61(K)=0.
IF (W66(MK) .GE. XM66) D61(K)=0.
IF (W67(MK) .GE. XM67) D61(K)=0.
X61(L) = X61(K) - D61(K) + Q61(K)
D62(K) = S62*(ALP7 - U7(K) - U7A(K))
W62(K) = X62(K) + Q62(K)
IF (W62(K) .GT. D62(K)) GO TO 132
IF (W62(K) .LT. D62(K)) D62(K) = W62(K)
132 X62(L) = X62(K) - D62(K) + Q62(K)
D63(K) = S63*(ALP7 - U7(K))
Q63(K) = 0.420*(D68(KN)+D71(KN))
IF (K .LE. 3) Q63(K) = Q630
W63(K) = X63(K) + Q63(K)
IF (W63(K) .GT. D63(K)) GO TO 134
IF (W63(K) .LT. D63(K)) D63(K) = W63(K)

```

Figure B-2. Continued.

```

134 X63(L) = X63(K) + Q63(K) - D63(K)
    D64(K) = S64*U7A(K)
    Q64(K) = 0.580*Q63(K)/0.420
    IF (K.LE. 3) Q64(K) = Q640
    W64(K) = X64(K) + Q64(K)
    IF (W64(K).GT. D64(K)) GO TO 136
    IF (W64(K).LT. D64(K)) D64(K) = W64(K)
136 X64(L) = X64(K) - D64(K) + Q64(K)
C
C *** INTERSECTION 497 DORR-SECOR
C
    D65(K) = S65*U8(K)
    Q65(K) = 0.436*(D61(KN)+D59(KN))
    IF (K.LE. 3) Q65(K) = Q650
    W65(K) = X65(K) + Q65(K)
    IF (W65(K).GT. D65(K)) GO TO 138
    IF (W65(K).LT. D65(K)) D65(K) = W65(K)
138 X65(L) = X65(K) - D65(K) + Q65(K)
    D66(K) = S66*U8(K)
    Q66(K) = 0.004*Q65(K)/0.436
    IF (K.LE. 3) Q66(K) = Q660
    W66(K) = X66(K) + Q66(K)
    IF (W66(K).GT. D66(K)) GO TO 140
    IF (W66(K).LT. D66(K)) D66(K) = W66(K)
140 X66(L) = X66(K) + Q66(K) - D66(K)
    D67(K) = S67*U8A(K)
    Q67(K) = 0.56*Q65(K)/0.436
    IF (K.LE. 3) Q67(K) = Q670
    W67(K) = X67(K) + Q67(K)
    IF (W67(K).GT. D67(K)) GO TO 142
    IF (W67(K).LT. D67(K)) D67(K) = W67(K)
142 X67(L) = X67(K) - D67(K) + Q67(K)
    D68(K) = S68*(U8(K) - U8A(K))
    W68(K) = X68(K) + Q68(K)
    IF (W68(K).GT. D68(K)) GO TO 144
    IF (W68(K).LT. D68(K)) D68(K) = W68(K)
144 IF (MK.LT. 1) W63(MK)=X63(1)+Q630
    IF (MK.LT. 1) W64(MK)=X64(1)+Q640
    IF (W63(MK).GE. XM63) D68(K)=0.
    IF (W64(MK).GE. XM64) D68(K)=0.
    X68(L) = X68(K) - D68(K) + Q68(K)
    D69(K) = S69*(U8(K) - U8A(K))
    W69(K) = X69(K) + Q69(K)
    IF (W69(K).GT. D69(K)) GO TO 146
    IF (W69(K).LT. D69(K)) D69(K) = W69(K)
146 X69(L) = X69(K) + Q69(K) - D69(K)
    D70(K) = S70*(ALP8 - U8(K))
    W70(K) = X70(K) + Q70(K)
    IF (W70(K).GT. D70(K)) GO TO 148
    IF (W70(K).LT. D70(K)) D70(K) = W70(K)
148 X70(L) = X70(K) + Q70(K) - D70(K)
    D71(K) = S71*(ALP8 - U8(K))
    W71(K) = X71(K) + Q71(K)
    IF (W71(K).GT. D71(K)) GO TO 150

```

Figure 1-2. Continued.

```

      IF (W71(K) .LT. D71(K)) D71(K) = W71(K)
150 IF (MK .LT. 1) W63(MK)=X63(1)+Q630
      IF (MK .LT. 1) W64(MK)=X64(1)+Q640
      IF (W63(MK) .GE. XM63) D71(K)=0.
      IF (W64(MK) .GE. XM64) D71(K)=0.
      X71(L) = X71(K) + Q71(K) - D71(K)
      D72(K) = S72*DEL8
      W72(K) = X72(K) + Q72(K)
      IF (W72(K) .GT. D72(K)) GO TO 152
      IF (W72(K) .LT. D72(K)) D72(K) = W72(K)
152 X72(L) = X72(K) + Q72(K) - D72(K)
      D73(K) = S73*(ALP8 - U8(K) - DEL8)
      W73(K) = X73(K) + Q73(K)
      IF (W73(K) .GT. D73(K)) GO TO 154
      IF (W73(K) .LT. D73(K)) D73(K) = W73(K)
154 X73(L) = X73(K) + Q73(K) - D73(K)
      D74(K) = S74*(ALP8 - U8(K) - DEL8)
      W74(K) = X74(K) + Q74(K)
      IF (W74(K) .GT. D74(K)) GO TO 156
      IF (W74(K) .LT. D74(K)) D74(K) = W74(K)
156 X74(L) = X74(K) + Q74(K) - D74(K)
200 CONTINUE
      P=0.
      DO 245 J=91,91
      P=W59(J)**2+W60(J)**2+W61(J)**2+W62(J)**2+R63*(W63(J)**2) -
1+R64*(W64(J)**2)+R65*(W65(J)**2)+R66*(W66(J)**2)+R67*(W67(J)**2) -
2+W68(J)**2+W69(J)**2+W70(J)**2+R71*(W71(J)**2)+W72(J)**2 -
3+W73(J)**2+W74(J)**2
245 CONTINUE
      DO 250 J=91,91
      P1=R7*((U7(J)-.0274)**2)+R7A*((U7A(J)-.051)**2) -
1 +R8*((U8(J)-.056)**2)+R8A*((U8A(J)-.0457)**2)
      P=P+P1
250 CONTINUE
      P=P/16.
      IF (P .LT. 1.000) P=P**.5
      TSPC = P
      RETURN
      END

```

Figure B-2. Concluded.

```

C *** THIS PROGRAM CALCULATES THE LENGTH OF THE QUEUES - BYRNE-DORR-
C SECOR INTERSECTIONS
C
  DIMENSION X59(92),X60(92),X61(92),X62(92),X63(92),X64(92), -
2X65(92),X66(92),X67(92),X68(92),X69(92),X70(92),X71(92),X72(92), -
3X73(92),X74(92),W59(92),W60(92),W61(92),W62(92),W63(92),W64(92), -
4W65(92),W66(92),W67(92),W68(92),W69(92),W70(92),W71(92),W72(92), -
5W73(92),W74(92),D59(92),D60(92),D61(92),D62(92),D63(92),D64(92), -
6D65(92),D66(92),D67(92),D68(92),D69(92),D70(92),D71(92),D72(92), -
7D73(92),D74(92),Q59(92),Q60(92),Q61(92),Q62(92),Q63(92),Q64(92), -
8Q65(92),Q66(92),Q67(92),Q68(92),Q69(92),Q70(92),Q71(92),Q72(92), -
9Q73(92),Q74(92),U7(92),U7A(92),U8(92),U8A(92)
  NAMELIST/CONT/U7,U7A,U8,U8A
  NAMELIST/INCON/X59,X60,X61,X62,X63,X64,X65,X66,X67,X68,X69,X70, -
1 X71,X72,X73,X74
  NAMELIST/INFLOW/Q59,Q60,Q61,Q62,Q63,Q64,Q65,Q66,Q67,Q68,Q69,-
1 Q70,Q71,Q72,Q73,Q74
  NAMELIST/WFCTR/R63,R64,R65,R66,R67,R71
  NAMELIST/SATRTS/S59,S60,S61,S62,S63,S64,S65,S66,S67,S68,S69,S70, -
1 S71,S72,S73,S74
  DATA X59(1),X60(1),X61(1),X62(1),X63(1)/5.,5.,10.,3.,10./
  DATA X64(1),X65(1),X66(1),X67(1),X68(1)/3.,10.,3.,3.,10./
  DATA X69(1),X70(1),X71(1),X72(1),X73(1),X74(1)/3.,5.,3.,3.,5.,3./
  DATA S59,S60,S61,S62,S63,S64,S65,S66/40.,40.,80.,25.,80.,25.,80.,25./
  DATA S67,S68,S69,S70,S71,S72,S73,S74/25.,80.,25.,40.,25.,25.,40.,25./
  DATA R63,R64,R65,R66,R67,R71/1.,1.,1.,1.,1.,1./
  DATA XM63,XM64,XM65,XM66,XM67/20.,8.,20.,8.,8./
  DATA R7,R7A,R8,R8A/0.,0.,0.,0./
  TFR = 10.
  U7(1) = .255/TFR
  U7A(1) = .493/TFR
  U8(1) = .560/TFR
  U8A(1) = .496/TFR
  Q59(1) = 9.78/TFR
  Q60(1) = 4.66/TFR
  Q61(1) = 10.3/TFR
  Q62(1) = 3.43/TFR
  Q63(1) = 10.48/TFR
  Q64(1) = 10.71/TFR
  Q65(1) = 8.34/TFR
  Q66(1) = .24/TFR
  Q67(1) = 11.79/TFR
  Q68(1) = 8.19/TFR
  Q69(1) = 3.18/TFR
  Q70(1) = .675/TFR
  Q71(1) = 12.8/TFR
  Q72(1) = 4.1/TFR
  Q73(1) = 1.84/TFR
  Q74(1) = .25/TFR
  ALP7 = 0.90/TFR
  ALP8 = 0.90/TFR
  DEL8 = 0.20/TFR
1 WRITE (2,3)
3 FORMAT (2X, 'ENTER CONTROL DATA')

```

Figure B-3.

```

      READ (2,CONT)
      WRITE (6,CONT)
      WRITE (2,8)
8  FORMAT (2X, 'ENTER INITIAL CONDITION DATA')
      READ (2,INCON)
      WRITE (6,INCON)
      WRITE (2,10)
10 FORMAT (2X, 'ENTER INFLOW DATA')
      READ (2,INFLOW)
      WRITE (6,INFLOW)
      WRITE (2,15)
15 FORMAT (2X, 'ENTER WFCTR DATA')
      READ (2,WFCTR)
      WRITE (6,WFCTR)
      WRITE (2,19)
19 FORMAT (2X, 'ENTER SATURATION RATE DATA')
      READ (2,SATRTE)
      WRITE (6,SATRTE)
      DO 100 K=1,91
        U7(K) = U7(1)
        U7A(K) = U7A(1)
        U8(K) = U8(1)
        U8A(K) = U8A(1)
        Q59(K) = Q59(1)
        Q60(K) = Q60(1)
        Q61(K) = Q61(1)
        Q62(K) = Q62(1)
        Q68(K) = Q68(1)
        Q69(K) = Q69(1)
        Q70(K) = Q70(1)
        Q71(K) = Q71(1)
        Q72(K) = Q72(1)
        Q73(K) = Q73(1)
        Q74(K) = Q74(1)
100 CONTINUE
      DO 200 K=1,91
        L=K+1
        MK=K-1
        KN=K-3
C
C *** INTERSECTION 478 BYRNE-DORR
C
      D59(K) = S59*U7(K)
      W59(K) = X59(K) + Q59(K)
      IF (W59(K) .GT. D59(K)) GO TO 126
      IF (W59(K) .LT. D59(K)) D59(K) = W59(K)
126 IF (MK .LT. 1) W65(MK)=X65(1)+Q650
      IF (MK .LT. 1) W66(MK)=X66(1)+Q660
      IF (MK .LT. 1) W67(MK)=X67(1)+Q670
      IF (W65(MK) .GE. XM65) D59(K)=0.
      IF (W66(MK) .GE. XM66) D59(K)=0.
      IF (W67(MK) .GE. XM67) D59(K)=0.
      X59(L) = X59(K) - D59(K) + Q59(K)
      D60(K) = S60*U7(K)

```

Figure B-3. Continued.



```

W60(K) = X60(K) + Q60(K)
IF (W60(K) .GT. D60(K)) GO TO 128
IF (W60(K) .LT. D60(K)) D60(K) = W60(K)
128 X60(L) = X60(K) - D60(K) + Q60(K)
D61(K) = S61*(ALP7 - U7(K) - U7A(K))
W61(K) = X61(K) + Q61(K)
IF (W61(K) .GT. D61(K)) GO TO 130
IF (W61(K) .LT. D61(K)) D61(K) = W61(K)
130 IF (MK .LT. 1) W65(MK) = X65(1) + Q650
IF (MK .LT. 1) W66(MK) = X66(1) + Q660
IF (MK .LT. 1) W67(MK) = X67(1) + Q670
IF (W65(MK) .GE. XM65) D61(K) = 0.
IF (W66(MK) .GE. XM66) D61(K) = 0.
IF (W67(MK) .GE. XM67) D61(K) = 0.
X61(L) = X61(K) - D61(K) + Q61(K)
D62(K) = S62*(ALP7 - U7(K) - U7A(K))
W62(K) = X62(K) + Q62(K)
IF (W62(K) .GT. D62(K)) GO TO 132
IF (W62(K) .LT. D62(K)) D62(K) = W62(K)
132 X62(L) = X62(K) - D62(K) + Q62(K)
D63(K) = S63*(ALP7 - U7(K))
Q63(K) = 0.420*(D68(KN) + D71(KN))
IF (K .LE. 3) Q63(K) = Q630
W63(K) = X63(K) + Q63(K)
IF (W63(K) .GT. D63(K)) GO TO 134
IF (W63(K) .LT. D63(K)) D63(K) = W63(K)
134 X63(L) = X63(K) + Q63(K) - D63(K)
D64(K) = S64*U7A(K)
Q64(K) = 0.580*Q63(K)/0.420
IF (K .LE. 3) Q64(K) = Q640
W64(K) = X64(K) + Q64(K)
IF (W64(K) .GT. D64(K)) GO TO 136
IF (W64(K) .LT. D64(K)) D64(K) = W64(K)
136 X64(L) = X64(K) - D64(K) + Q64(K)
C
C *** INTERSECTION 497 DORR-SECOR
C
D65(K) = S65*U8(K)
Q65(K) = 0.436*(D61(KN) + D59(KN))
IF (K .LE. 3) Q65(K) = Q650
W65(K) = X65(K) + Q65(K)
IF (W65(K) .GT. D65(K)) GO TO 138
IF (W65(K) .LT. D65(K)) D65(K) = W65(K)
138 X65(L) = X65(K) - D65(K) + Q65(K)
D66(K) = S66*U8(K)
Q66(K) = 0.004*Q65(K)/0.436
IF (K .LE. 3) Q66(K) = Q660
W66(K) = X66(K) + Q66(K)
IF (W66(K) .GT. D66(K)) GO TO 140
IF (W66(K) .LT. D66(K)) D66(K) = W66(K)
140 X66(L) = X66(K) + Q66(K) - D66(K)
D67(K) = S67*U8A(K)
Q67(K) = 0.56*Q65(K)/0.436
IF (K .LE. 3) Q67(K) = Q670

```

Figure B-3. Continued.

```

W67(K) = X67(K) + Q67(K)
IF (W67(K) .GT. D67(K)) GO TO 142
IF (W67(K) .LT. D67(K)) D67(K) = W67(K)
142 X67(L) = X67(K) - D67(K) + Q67(K)
D68(K) = S68*(U8(K) - U8A(K))
W68(K) = X68(K) + Q68(K)
IF (W68(K) .GT. D68(K)) GO TO 144
IF (W68(K) .LT. D68(K)) D68(K) = W68(K)
144 IF (MK .LT. 1) W63(MK)=X63(1)+Q630
IF (MK .LT. 1) W64(MK)=X64(1)+Q640
IF (W63(MK) .GE. XM63) D68(K)=0.
IF (W64(MK) .GE. XM64) D68(K)=0.
X68(L) = X68(K) - D68(K) + Q68(K)
D69(K) = S69*(U8(K) - U8A(K))
W69(K) = X69(K) + Q69(K)
IF (W69(K) .GT. D69(K)) GO TO 146
IF (W69(K) .LT. D69(K)) D69(K) = W69(K)
146 X69(L) = X69(K) + Q69(K) - D69(K)
D70(K) = S70*(ALP8 - U8(K))
W70(K) = X70(K) + Q70(K)
IF (W70(K) .GT. D70(K)) GO TO 148
IF (W70(K) .LT. D70(K)) D70(K) = W70(K)
148 X70(L) = X70(K) + Q70(K) - D70(K)
D71(K) = S71*(ALP8 - U8(K))
W71(K) = X71(K) + Q71(K)
IF (W71(K) .GT. D71(K)) GO TO 150
IF (W71(K) .LT. D71(K)) D71(K) = W71(K)
150 IF (MK .LT. 1) W63(MK)=X63(1)+Q630
IF (MK .LT. 1) W64(MK)=X64(1)+Q640
IF (W63(MK) .GE. XM63) D71(K)=0.
IF (W64(MK) .GE. XM64) D71(K)=0.
X71(L) = X71(K) + Q71(K) - D71(K)
D72(K) = S72*DEL8
W72(K) = X72(K) + Q72(K)
IF (W72(K) .GT. D72(K)) GO TO 152
IF (W72(K) .LT. D72(K)) D72(K) = W72(K)
152 X72(L) = X72(K) + Q72(K) - D72(K)
D73(K) = S73*(ALP8 - U8(K) - DEL8)
W73(K) = X73(K) + Q73(K)
IF (W73(K) .GT. D73(K)) GO TO 154
IF (W73(K) .LT. D73(K)) D73(K) = W73(K)
154 X73(L) = X73(K) + Q73(K) - D73(K)
D74(K) = S74*(ALP8 - U8(K) - DEL8)
W74(K) = X74(K) + Q74(K)
IF (W74(K) .GT. D74(K)) GO TO 156
IF (W74(K) .LT. D74(K)) D74(K) = W74(K)
156 X74(L) = X74(K) + Q74(K) - D74(K)
200 CONTINUE
P=0.
DO 245 J=91,91
P=W59(J)**2+W60(J)**2+W61(J)**2+W62(J)**2+R63*(W63(J)**2) -
1+R64*(W64(J)**2)+R65*(W65(J)**2)+R66*(W66(J)**2)+R67*(W67(J)**2) -
2+W68(J)**2+W69(J)**2+W70(J)**2+R71*(W71(J)**2)+W72(J)**2 -
3+W73(J)**2+W74(J)**2

```

Figure B-3. Continued.

```

245 CONTINUE
DO 250 J=91,91
P1=R7*((U7(J)-.0274)**2)+R7A*((U7A(J)-.051)**2)
1 +R8*((U8(J)-.056)**2)+R8A*((U8A(J)-.0457)**2)
P=P+P1
250 CONTINUE
P=P/16.
IF (P .LT. 1.000) P=P**.5
WRITE (6,229)
229 FORMAT (1H0)
WRITE (6,660) P
WRITE (6,229)
WRITE (6,219)
219 FORMAT (6X,'J',8X,'X59(J)',4X,'X60(J)',4X,'X61(J)',4X,'X62(J)',
1 4X,'X63(J)',4X,'X64(J)',4X,'X65(J)',4X,'X66(J)',4X,'X67(J)',
24X,'X68(J)',//)
DO 235 J=1,10
WRITE (6,639) J,X59(J),X60(J),X61(J),X62(J),X63(J),X64(J),X65(J),
1 X66(J),X67(J),X68(J)
235 CONTINUE
DO 236 J=11,91,10
WRITE (6,639) J,X59(J),X60(J),X61(J),X62(J),X63(J),X64(J),X65(J),
1 X66(J),X67(J),X68(J)
236 CONTINUE
WRITE (6,229)
WRITE (6,249)
249 FORMAT (6X,'J',8X,'X69(J)',4X,'X70(J)',4X,'X71(J)',4X,'X72(J)',
1 4X,'X73(J)',4X,'X74(J)',//)
DO 255 J=1,10
WRITE (6,649) J,X69(J),X70(J),X71(J),X72(J),X73(J),X74(J)
255 CONTINUE
DO 256 J=11,91,10
WRITE (6,649) J,X69(J),X70(J),X71(J),X72(J),X73(J),X74(J)
256 CONTINUE
WRITE (6,229)
WRITE (6,400)
400 FORMAT (6X,'J',8X,'W59(J)',4X,'W60(J)',4X,'W61(J)',4X,'W62(J)',
1 4X,'W63(J)',4X,'W64(J)',4X,'W65(J)',4X,'W66(J)',4X,'W67(J)',
2 4X,'W68(J)',//)
DO 405 J=1,10
WRITE (6,639) J,W59(J),W60(J),W61(J),W62(J),W63(J),W64(J),W65(J),
1 W66(J),W67(J),W68(J)
405 CONTINUE
DO 410 J=11,91,10
WRITE (6,639) J,W59(J),W60(J),W61(J),W62(J),W63(J),W64(J),W65(J),
1 W66(J),W67(J),W68(J)
410 CONTINUE
WRITE (6,229)
WRITE (6,415)
415 FORMAT (6X,'J',8X,'W69(J)',4X,'W70(J)',4X,'W71(J)',4X,'W72(J)',
1 4X,'W73(J)',4X,'W74(J)',//)
DO 420 J=1,10
WRITE (6,649) J,W69(J),W70(J),W71(J),W72(J),W73(J),W74(J)
420 CONTINUE

```

Figure B-3. Continued.

```

DO 425 J=11,91,10
WRITE (6,649) J,W69(J),W70(J),W71(J),W72(J),W73(J),W74(J)
425 CONTINUE
WRITE (6,229)
WRITE (6,550)
550 FORMAT (6X,'J',8X,'D59(J)',4X,'D60(J)',4X,'D61(J)',4X,'D62(J)', -
1 4X,'D63(J)',4X,'D64(J)',4X,'D65(J)',4X,'D66(J)',4X,'D67(J)', -
2 4X,'D68(J)')//)
DO 555 J=1,10
WRITE (6,639) J,D59(J),D60(J),D61(J),D62(J),D63(J),D64(J),D65(J), -
1 D66(J),D67(J),D68(J)
555 CONTINUE
DO 560 J=11,91,10
WRITE (6,639) J,D59(J),D60(J),D61(J),D62(J),D63(J),D64(J),D65(J), -
1 D66(J),D67(J),D68(J)
560 CONTINUE
WRITE (6,229)
WRITE (6,565)
565 FORMAT (6X,'J',8X,'D69(J)',4X,'D70(J)',4X,'D71(J)',4X,'D72(J)', -
2 4X,'D73(J)',4X,'D74(J)')//)
DO 570 J=1,10
WRITE (6,649) J,D69(J),D70(J),D71(J),D72(J),D73(J),D74(J)
570 CONTINUE
DO 575 J=11,91,10
WRITE (6,649) J,D69(J),D70(J),D71(J),D72(J),D73(J),D74(J)
575 CONTINUE
WRITE (6,229)
WRITE (6,675)
675 FORMAT (6X,'J',8X,'Q63(J)',4X,'Q64(J)',4X,'Q65(J)',4X,'Q66(J)', -
1 4X,'Q67(J)')//)
DO 680 J=1,10
WRITE (6,689) J,Q63(J),Q64(J),Q65(J),Q66(J),Q67(J)
680 CONTINUE
DO 685 J=11,91,10
WRITE (6,689) J,Q63(J),Q64(J),Q65(J),Q66(J),Q67(J)
685 CONTINUE
639 FORMAT (4X,I3,5X,10(F8.2,2X))
649 FORMAT (4X,I3,5X,5(F8.2,2X))
660 FORMAT (6X,3HP=,F6.2)
689 FORMAT (4X,I3,5X,5(F8.2,2X))
GO TO 1
END

```

Figure B-3. Concluded.

APPENDIX C - LISTING OF COMPUTER PROGRAMS - SECTION I

```
C
C *** CALL PROGRAM FOR OPTIMIZATION OF TRAFFIC MODEL - SECTION I
C
  IMPLICIT REAL*8 (A-H,O-Z)
  EXTERNAL TMIN
  DIMENSION U(16),WA(320)
  N=16
  EPS=.001
  ITMAX=100
  U(1)=.0676
  U(2)=.070
  U(3)=.0294
  U(4)=.0136
  U(5)=.0622
  U(6)=.0700
  U(7)=.0412
  U(8)=.0152
  U(9)=.0150
  U(10)=.0350
  U(11)=.022
  U(12)=.0395
  U(13)=.0678
  U(14)=.0370
  U(15)=.0112
  U(16)=.0648
  CALL ZXPOWL (TMIN,EPS,N,U,FMIN,ITMAX,WA,IER)
  WRITE (6,100) FMIN,ITMAX
100 FORMAT (2X, 'FMIN= ',G12.5, 'ITMAX= ',I3)
  STOP
  END
```

Figure C-1.

## C \*\*\* FUNCTION FOR OPTIMIZATION - SECTION I

C

```

DOUBLE PRECISION FUNCTION TMIN(U)
DOUBLE PRECISION U
DIMENSION U(16)
DIMENSION X1(92), X2(92), X3(92), X4(92), X5(92), X6(92), X7(92), -
1X8(92), X9(92), X10(92), X11(92), X12(92), X13(92), X14(92), X15(92), -
2X16(92), X17(92), X18(92), X19(92), X20(92), X21(92), X22(92), X23(92), -
3X24(92), X25(92), X26(92), X27(92), X28(92), X29(92), X30(92), X31(92), -
4X32(92), X33(92), X34(92), X35(92), X36(92), X37(92), X38(92), X39(92), -
5X40(92), X41(92), X42(92), X43(92), X44(92), X45(92), X46(92), X47(92), -
6X48(92), X49(92), X50(92), X51(92), X52(92), X53(92), X54(92), X55(92), -
7X56(92), X57(92), X58(92), X59(92), X60(92), X61(92), X62(92), X63(92), -
8X64(92), X65(92), X66(92), X67(92), X68(92), X69(92), X70(92), X71(92), -
9X72(92), X73(92), X74(92), X75(92), X76(92), X77(92), X78(92), X79(92), -
AX80(92), X81(92), X82(92), X83(92), X84(92), X85(92), X86(92), X87(92), -
BX88(92), X89(92), X90(92), X91(92), X92(92), X93(92), X94(92), X95(92), -
CX96(92), X97(92), X98(92)
DIMENSION W1(92), W2(92), W3(92), W4(92), W5(92), W6(92), W7(92), -
1W8(92), W9(92), W10(92), W11(92), W12(92), W13(92), W14(92), W15(92), -
2W16(92), W17(92), W18(92), W19(92), W20(92), W21(92), W22(92), W23(92), -
3W24(92), W25(92), W26(92), W27(92), W28(92), W29(92), W30(92), W31(92), -
4W32(92), W33(92), W34(92), W35(92), W36(92), W37(92), W38(92), W39(92), -
5W40(92), W41(92), W42(92), W43(92), W44(92), W45(92), W46(92), W47(92), -
6W48(92), W49(92), W50(92), W51(92), W52(92), W53(92), W54(92), W55(92), -
7W56(92), W57(92), W58(92), W59(92), W60(92), W61(92), W62(92), W63(92), -
8W64(92), W65(92), W66(92), W67(92), W68(92), W69(92), W70(92), W71(92), -
9W72(92), W73(92), W74(92), W75(92), W76(92), W77(92), W78(92), W79(92), -
AW80(92), W81(92), W82(92), W83(92), W84(92), W85(92), W86(92), W87(92), -
BW88(92), W89(92), W90(92), W91(92), W92(92), W93(92), W94(92), W95(92), -
CW96(92), W97(92), W98(92)
DIMENSION D1(92), D2(92), D3(92), D4(92), D5(92), D6(92), D7(92), -
1D8(92), D9(92), D10(92), D11(92), D12(92), D13(92), D14(92), D15(92), -
2D16(92), D17(92), D18(92), D19(92), D20(92), D21(92), D22(92), D23(92), -
3D24(92), D25(92), D26(92), D27(92), D28(92), D29(92), D30(92), D31(92), -
4D32(92), D33(92), D34(92), D35(92), D36(92), D37(92), D38(92), D39(92), -
5D40(92), D41(92), D42(92), D43(92), D44(92), D45(92), D46(92), D47(92), -
6D48(92), D49(92), D50(92), D51(92), D52(92), D53(92), D54(92), D55(92), -
7D56(92), D57(92), D58(92), D59(92), D60(92), D61(92), D62(92), D63(92), -
8D64(92), D65(92), D66(92), D67(92), D68(92), D69(92), D70(92), D71(92), -
9D72(92), D73(92), D74(92), D75(92), D76(92), D77(92), D78(92), D79(92), -
AD80(92), D81(92), D82(92), D83(92), D84(92), D85(92), D86(92), D87(92), -
BD88(92), D89(92), D90(92), D91(92), D92(92), D93(92), D94(92), D95(92), -
CD96(92), D97(92), D98(92)
DIMENSION Q1(92), Q2(92), Q3(92), Q4(92), Q5(92), Q6(92), Q7(92), -
1Q8(92), Q9(92), Q10(92), Q11(92), Q12(92), Q13(92), Q14(92), Q15(92), -
2Q16(92), Q17(92), Q18(92), Q19(92), Q20(92), Q21(92), Q22(92), Q23(92), -
3Q24(92), Q25(92), Q26(92), Q27(92), Q28(92), Q29(92), Q30(92), Q31(92), -
4Q32(92), Q33(92), Q34(92), Q35(92), Q36(92), Q37(92), Q38(92), Q39(92), -
5Q40(92), Q41(92), Q42(92), Q43(92), Q44(92), Q45(92), Q46(92), Q47(92), -
6Q48(92), Q49(92), Q50(92), Q51(92), Q52(92), Q53(92), Q54(92), Q55(92), -
7Q56(92), Q57(92), Q58(92), Q59(92), Q60(92), Q61(92), Q62(92), Q63(92), -
8Q64(92), Q65(92), Q66(92), Q67(92), Q68(92), Q69(92), Q70(92), Q71(92), -
9Q72(92), Q73(92), Q74(92), Q75(92), Q76(92), Q77(92), Q78(92), Q79(92), -

```

Figure C-2.

AQ80 (92), Q81 (92), Q82 (92), Q83 (92), Q84 (92), Q85 (92), Q86 (92), Q87 (92), -  
 BQ88 (92), Q89 (92), Q90 (92), Q91 (92), Q92 (92), Q93 (92), Q94 (92), Q95 (92), -  
 CQ96 (92), Q97 (92), Q98 (92), U1 (92), U2 (92), U3 (92), U3A (92), U4 (92), -  
 DU5 (92), U6 (92), U6A (92), U7 (92), U7A (92), U8 (92), U8A (92), U9 (92), -  
 EU10 (92), U10A (92), U11 (92)  
 DATA R1, R2, R3, R3A, R4, R5/1000., 1000., 1000., 1000., 1000., 1000./  
 DATA R6, R6A, R7, R7A, R8, R8A/1000., 1000., 1000., 1000., 10000., 10000./  
 DATA R9, R10, R10A, R11/1000., 1000., 1000., 1000./  
 DATA X1 (1), X2 (1), X3 (1), X4 (1), X5 (1), X6 (1)/10., 3., 10., 3., 3., 5./  
 DATA X7 (1), X8 (1), X9 (1), X10 (1), X11 (1)/3., 3., 5., 3., 10./  
 DATA X12 (1), X13 (1), X14 (1), X15 (1), X16 (1)/3., 10., 3., 3., 3./  
 DATA X17 (1), X18 (1), X19 (1), X20 (1), X21 (1)/10., 3., 3., 10., 3./  
 DATA X22 (1), X23 (1), X24 (1), X25 (1), X26 (1)/3., 10., 3., 3., 10./  
 DATA X27 (1), X28 (1), X29 (1), X30 (1), X31 (1)/3., 3., 16., 3., 10./  
 DATA X32 (1), X33 (1), X34 (1), X35 (1), X36 (1)/3., 5., 3., 3., 5./  
 DATA X37 (1), X38 (1), X39 (1), X40 (1), X41 (1)/3., 3., 5., 3., 5./  
 DATA X42 (1), X43 (1), X44 (1), X45 (1), X46 (1)/3., 10., 3., 10., 3./  
 DATA X47 (1), X48 (1), X49 (1), X50 (1), X51 (1)/10., 3., 3., 10., 3./  
 DATA X52 (1), X53 (1), X54 (1), X55 (1), X56 (1)/3., 10., 3., 3., 10./  
 DATA X57 (1), X58 (1), X59 (1), X60 (1), X61 (1)/3., 3., 5., 5., 10./  
 DATA X62 (1), X63 (1), X64 (1), X65 (1), X66 (1)/3., 10., 3., 10., 3./  
 DATA X67 (1), X68 (1), X69 (1), X70 (1), X71 (1)/3., 10., 3., 5., 3./  
 DATA X72 (1), X73 (1), X74 (1), X75 (1), X76 (1)/3., 5., 3., 10., 3./  
 DATA X77 (1), X78 (1), X79 (1), X80 (1), X81 (1)/10., 3., 3., 3., 10./  
 DATA X82 (1), X83 (1), X84 (1), X85 (1), X86 (1)/3., 3., 10., 3., 3./  
 DATA X87 (1), X88 (1), X89 (1), X90 (1), X91 (1)/10., 3., 3., 10., 3./  
 DATA X92 (1), X93 (1), X94 (1), X95 (1), X96 (1)/3., 10., 3., 10., 3./  
 DATA X97 (1), X98 (1)/3., 3./  
 DATA XM13, XM14, XM26, XM27, XM28/40., 16., 40., 16., 16./  
 DATA XM63, XM64, XM65, XM66, XM67/40., 16., 40., 16., 16./  
 DATA S1, S2, S3, S4, S5, S6, S7/80., 25., 80., 25., 25., 40., 25./  
 DATA S8, S9, S10, S11, S12, S13, S14/25., 40., 25., 80., 25., 80., 25./  
 DATA S15, S16, S17, S18, S19, S20, S21/40., 40., 80., 25., 25., 80., 25./  
 DATA S22, S23, S24, S25, S26, S27, S28/40., 80., 40., 25., 80., 25., 40./  
 DATA S29, S30, S31, S32, S33, S34, S35/80., 25., 80., 25., 40., 25., 25./  
 DATA S36, S37, S38, S39, S40, S41, S42/40., 25., 40., 40., 25., 40., 25./  
 DATA S43, S44, S45, S46, S47, S48, S49/80., 25., 80., 25., 80., 25., 25./  
 DATA S50, S51, S52, S53, S54, S55, S56/80., 25., 25., 80., 25., 40., 80./  
 DATA S57, S58, S59, S60, S61, S62, S63/25., 40., 40., 40., 80., 25., 80./  
 DATA S64, S65, S66, S67, S68, S69, S70/40., 80., 25., 40., 80., 25., 40./  
 DATA S71, S72, S73, S74, S75, S76, S77/40., 40., 40., 25., 80., 25., 80./  
 DATA S78, S79, S80, S81, S82, S83, S84/25., 40., 40., 80., 25., 25., 80./  
 DATA S85, S86, S87, S88, S89, S90, S91/25., 25., 80., 25., 25., 80., 25./  
 DATA S92, S93, S94, S95, S96, S97, S98/25., 80., 25., 80., 25., 25., 25./  
 TFR=10.  
 Q1 (1) = 9.2/TFR  
 Q2 (1) = 0.85/TFR  
 Q6 (1) = 2.48/TFR  
 Q7 (1) = 1.08/TFR  
 Q8 (1) = .85/TFR  
 Q9 (1) = 2.26/TFR  
 Q10 (1) = 1.28/TFR  
 Q15 (1) = 2.0/TFR  
 Q16 (1) = 2.0/TFR

Figure C-2. Continued.

Q30A = 9.08/TFR  
Q40A = 1.9/TFR  
Q50A = .975/TFR  
Q110 = 12.36/TFR  
Q120 = 2.24/TFR  
Q130 = 11.59/TFR  
Q140 = 1.57/TFR  
Q17(1) = 6.61/TFR  
Q18(1) = 2.08/TFR  
Q19(1) = 1.75/TFR  
Q200 = 5.23/TFR  
Q210 = 2.44/TFR  
Q220 = 4.6/TFR  
Q230 = 9.15/TFR  
Q240 = 4.1/TFR  
Q250 = 1.9/TFR  
Q260 = 9.54/TFR  
Q270 = 0.73/TFR  
Q280 = 2.25/TFR  
Q290 = 8.73/TFR  
Q300 = .66/TFR  
Q310 = 9.45/TFR  
Q320 = 2.11/TFR  
Q330 = 1.3/TFR  
Q340 = 0.525/TFR  
Q350 = .663/TFR  
Q36(1) = 1.61/TFR  
Q37(1) = 1.19/TFR  
Q38(1) = 1.46/TFR  
Q39(1) = 0.5/TFR  
Q40(1) = 1.86/TFR  
Q41(1) = 0.5/TFR  
Q42(1) = .025/TFR  
Q430 = 15.58/TFR  
Q440 = 1.09/TFR  
Q450 = 16.03/TFR  
Q460 = 1.75/TFR  
Q47(1) = 2.78/TFR  
Q48(1) = 1.20/TFR  
Q49(1) = 0.66/TFR  
Q500 = 3.29/TFR  
Q510 = 2.99/TFR  
Q520 = 2.69/TFR  
Q53(1) = 11.86/TFR  
Q54(1) = 2.29/TFR  
Q55(1) = 1.11/TFR  
Q560 = 11.96/TFR  
Q570 = 0.80/TFR  
Q580 = 3.05/TFR  
Q590 = 9.78/TFR  
Q600 = 4.66/TFR  
Q610 = 10.3/TFR  
Q620 = 3.43/TFR  
Q630 = 10.48/TFR

Figure C-2. Continued.



Q640 = 10.71/TFR  
Q650 = 8.34/TFR  
Q660 = .24/TFR  
Q670 = 11.79/TFR  
Q68(1) = 8.19/TFR  
Q69(1) = 3.18/TFR  
Q70(1) = .675/TFR  
Q71(1) = 12.8/TFR  
Q72(1) = 4.1/TFR  
Q73(1) = 1.84/TFR  
Q74(1) = .25/TFR  
Q750 = 11.13/TFR  
Q760 = 1.19/TFR  
Q770 = 12.49/TFR  
Q780 = 3.24/TFR  
Q79(1) = 2.09/TFR  
Q80(1) = 2.99/TFR  
Q810 = 5.20/TFR  
Q820 = 3.11/TFR  
Q830 = 1.78/TFR  
Q84(1) = 5.76/TFR  
Q85(1) = 1.91/TFR  
Q86(1) = 4.91/TFR  
Q87(1) = 12.84/TFR  
Q88(1) = 3.84/TFR  
Q89(1) = 2.46/TFR  
Q900 = 13.14/TFR  
Q910 = 1.84/TFR  
Q920 = 1.65/TFR  
Q930 = 6.16/TFR  
Q940 = 2.64/TFR  
Q950 = 4.2/TFR  
Q960 = 1.8/TFR  
Q97(1) = 2.0/TFR  
Q98(1) = 2.0/TFR  
ALP1 = 0.90/TFR  
ALP2 = 0.90/TFR  
ALP3 = 0.90/TFR  
ALP4 = 0.90/TFR  
ALP5 = 0.90/TFR  
ALP6 = 0.90/TFR  
ALP7 = 0.90/TFR  
ALP8 = 0.90/TFR  
ALP9 = 0.80/TFR  
ALP10 = 0.90/TFR  
ALP11 = 0.90/TFR  
DEL1 = 0.15/TFR  
DEL2 = 0.15/TFR  
DEL3 = 0.10/TFR  
DEL4 = 0.15/TFR  
DEL5 = 0.15/TFR  
DEL6 = 0.15/TFR  
DEL8 = 0.15/TFR  
DEL9 = 0.15/TFR

Figure C-2. Continued.

DEL10 = 0.25/TFR  
 DEL11 = 0.20/TFR  
 U1(1) = U(1)  
 U2(1) = U(2)  
 U3(1) = U(3)  
 U3A(1) = U(4)  
 U4(1) = U(5)  
 U5(1) = U(6)  
 U6(1) = U(7)  
 U6A(1) = U(8)  
 U7(1) = U(9)  
 U7A(1) = U(10)  
 U8(1) = U(11)  
 U8A(1) = U(12)  
 U9(1) = U(13)  
 U10(1) = U(14)  
 U10A(1) = U(15)  
 U11(1) = U(16)  
 DO 8 K = 1,91  
 U1(K) = U1(1)  
 U2(K) = U2(1)  
 U3(K) = U3(1)  
 U3A(K) = U3A(1)  
 U4(K) = U4(1)  
 U5(K) = U5(1)  
 U6(K) = U6(1)  
 U6A(K) = U6A(1)  
 U7(K) = U7(1)  
 U7A(K) = U7A(1)  
 U8(K) = U8(1)  
 U8A(K) = U8A(1)  
 U9(K) = U9(1)  
 U10(K) = U10(1)  
 U10A(K) = U10A(1)  
 U11(K) = U11(1)  
 Q1(K) = Q1(1)  
 Q2(K) = Q2(1)  
 Q6(K) = Q6(1)  
 Q7(K) = Q7(1)  
 Q8(K) = Q8(1)  
 Q9(K) = Q9(1)  
 Q10(K) = Q10(1)  
 Q15(K) = Q15(1)  
 Q16(K) = Q16(1)  
 Q17(K) = Q17(1)  
 Q18(K) = Q18(1)  
 Q19(K) = Q19(1)  
 Q36(K) = Q36(1)  
 Q37(K) = Q37(1)  
 Q38(K) = Q38(1)  
 Q39(K) = Q39(1)  
 Q40(K) = Q40(1)  
 Q41(K) = Q41(1)  
 Q42(K) = Q42(1)

Figure C-2. Continued.

```

Q47(K) = Q47(1)
Q48(K) = Q48(1)
Q49(K) = Q49(1)
Q53(K) = Q53(1)
Q54(K) = Q54(1)
Q55(K) = Q55(1)
Q68(K) = Q68(1)
Q69(K) = Q69(1)
Q70(K) = Q70(1)
Q71(K) = Q71(1)
Q72(K) = Q72(1)
Q73(K) = Q73(1)
Q74(K) = Q74(1)
Q79(K) = Q79(1)
Q80(K) = Q80(1)
Q84(K) = Q84(1)
Q85(K) = Q85(1)
Q86(K) = Q86(1)
Q87(K) = Q87(1)
Q88(K) = Q88(1)
Q89(K) = Q89(1)
Q97(K) = Q97(1)
Q98(K) = Q97(1)
8 CONTINUE
DO 200 K=1,91
  L=K+1
  MK=K-1
  MM=K-2
  KN=K-3
  M=K-4
  KL=K-5
  KM=K-7
  MN=K-11
  JJ=K-13
  JK=K-15
  JM=K-17
  JL=K-20
C
C *** INTERSECTION 507 REYNOLDS-BANCROFT
C
  D1(K) = S1*(U1(K) - DEL1)
  W1(K) = X1(K) + Q1(K)
  IF (W1(K) .GT. D1(K)) GO TO 10
  IF (W1(K) .LT. D1(K)) D1(K) = W1(K)
10 X1(L) = X1(K) - D1(K) + Q1(K)
  D2(K) = S2*(U1(K) - DEL1)
  W2(K) = X2(K) + Q2(K)
  IF (W2(K) .GT. D2(K)) GO TO 12
  IF (W2(K) .LT. D2(K)) D2(K) = W2(K)
12 X2(L) = X2(K) - D2(K) + Q2(K)
  Q3(K) = 0.76*(D13(M) + D15(M))
  IF (K .LE. 4) Q3(K) = Q30A
  Q4(K) = 0.17*Q3(K)/0.76
  IF (K .LE. 4) Q4(K) = Q40A

```

Figure C-2. Continued.

```

Q5(K) = 0.07*Q3(K)/0.76
IF (K .LE. 4) Q5(K) = Q50A
D3(K) = S3*U1(K)
W3(K) = X3(K) + Q3(K)
IF (W3(K) .GT. D3(K)) GO TO 14
IF (W3(K) .LT. D3(K)) D3(K) = W3(K)
14 X3(L) = X3(K) - D3(K) + Q3(K)
D4(K) = S4*U1(K)
W4(K) = X4(K) + Q4(K)
IF (W4(K) .GT. D4(K)) GO TO 16
IF (W4(K) .LT. D4(K)) D4(K) = W4(K)
16 X4(L) = X4(K) - D4(K) + Q4(K)
D5(K) = S5*DEL1
W5(K) = X5(K) + Q5(K)
IF (W5(K) .GT. D5(K)) GO TO 18
IF (W5(K) .LT. D5(K)) D5(K) = W5(K)
18 X5(L) = X5(K) + Q5(K) - D5(K)
D6(K) = S6*(ALP1 - U1(K))
W6(K) = X6(K) + Q6(K)
IF (W6(K) .GT. D6(K)) GO TO 20
IF (W6(K) .LT. D6(K)) D6(K) = W6(K)
20 X6(L) = X6(K) - D6(K) + Q6(K)
D7(K) = S7*(ALP1 - U1(K))
W7(K) = X7(K) + Q7(K)
IF (W7(K) .GT. D7(K)) GO TO 22
IF (W7(K) .LT. D7(K)) D7(K) = W7(K)
22 X7(L) = X7(K) - D7(K) + Q7(K)
D8(K) = S8*DEL1
W8(K) = X8(K) + Q8(K)
IF (W8(K) .GT. D8(K)) GO TO 24
IF (W8(K) .LT. D8(K)) D8(K) = W8(K)
24 X8(L) = X8(K) + Q8(K) - D8(K)
D9(K) = S9*(ALP1 - DEL1 - U1(K))
W9(K) = X9(K) + Q9(K)
IF (W9(K) .GT. D9(K)) GO TO 26
IF (W9(K) .LT. D9(K)) D9(K) = W9(K)
26 X9(L) = X9(K) - D9(K) + Q9(K)
D10(K) = S10*(ALP1 - DEL1 - U1(K))
W10(K) = X10(K) + Q10(K)
IF (W10(K) .GT. D10(K)) GO TO 28
IF (W10(K) .LT. D10(K)) D10(K) = W10(K)
28 X10(L) = X10(K) - D10(K) + Q10(K)

C
C *** INTERSECTION 514 REYNOLDS-GLANN SCHOOL
C
D11(K) = S11*(U2(K) - DEL2)
Q11(K) = .750*(D1(K) + D7(K))
IF (K .LE. 4) Q11(K) = Q110
Q12(K) = .250*Q11(K)/.750
IF (K .LE. 4) Q12(K) = Q120
W11(K) = X11(K) + Q11(K)
IF (W11(K) .GT. D11(K)) GO TO 30
IF (W11(K) .LT. D11(K)) D11(K) = W11(K)
30 IF (MK .LT. 1) W26(MK) = X26(1) + Q260

```

Figure C-2. Continued.

```

IF (MK .LT. 1) W27(MK)=X27(1)+Q270
IF (MK .LT. 1) W28(MK)=X28(1)+Q280
IF (W26(MK) .GE. XM26) D11(K)=0.
IF (W27(MK) .GE. XM27) D11(K)=0.
IF (W28(MK) .GE. XM28) D11(K)=0.
X11(L) = X11(K) + Q11(K) - D11(K)
D12(K) = S12*(U2(K) - DEL2)
W12(K) = X12(K) + Q12(K)
IF (W12(K) .GT. D12(K)) GO TO 32
IF (W12(K) .LT. D12(K)) D12(K) = W12(K)
32 X12(L) = X12(K) + Q12(K) - D12(K)
Q13(K) = .900*(D23(MM) + D19(MM) + D21(MM))
IF (K .LE. 2) Q13(K) = Q130
Q14(K) = .100*Q13(K)/.900
IF (K .LE. 2) Q14(K)=Q140
D13(K) = S13*U2(K)
W13(K) = X13(K) + Q13(K)
IF (W13(K) .GT. D13(K)) GO TO 34
IF (W13(K) .LT. D13(K)) D13(K) = W13(K)
34 X13(L) = X13(K) + Q13(K) - D13(K)
D14(K) = S14*DEL2
W14(K) = X14(K) + Q14(K)
IF (W14(K) .GT. D14(K)) GO TO 36
IF (W14(K) .LT. D14(K)) D14(K) = W14(K)
36 X14(L) = X14(K) + Q14(K) - D14(K)
D15(K) = S15*(ALP2 - U2(K))
W15(K) = X15(K) + Q15(K)
IF (W15(K) .GT. D15(K)) GO TO 38
IF (W15(K) .LT. D15(K)) D15(K) = W15(K)
38 X15(L) = X15(K) + Q15(K) - D15(K)
D16(K) = S16*(ALP2 - U2(K))
W16(K) = X16(K) + Q16(K)
IF (W16(K) .GT. D16(K)) GO TO 40
IF (W16(K) .LT. D16(K)) D16(K) = W16(K)
40 IF (MK .LT. 1) W26(MK)=X26(1)+Q260
IF (MK .LT. 1) W27(MK)=X27(1)+Q270
IF (MK .LT. 1) W28(MK)=X28(1)+Q280
IF (W26(MK) .GE. XM26) D16(K)=0.
IF (W27(MK) .GE. XM27) D16(K)=0.
IF (W28(MK) .GE. XM28) D16(K)=0.
X16(L) = X16(K) + Q16(K) - D16(K)
C
C *** INTERSECTION 512 REYNOLDS-DORR
C
D17(K) = S17*U3(K)
W17(K) = X17(K) + Q17(K)
IF (W17(K) .GT. D17(K)) GO TO 42
IF (W17(K) .LT. D17(K)) D17(K) = W17(K)
42 X17(L) = X17(K) - D17(K) + Q17(K)
D18(K) = S18*U3(K)
W18(K) = X18(K) + Q18(K)
IF (W18(K) .GT. D18(K)) GO TO 44
IF (W18(K) .LT. D18(K)) D18(K) = W18(K)
44 X18(L) = X18(K) - D18(K) + Q18(K)

```

Figure C-2. Continued.

```

D19(K) = S19*U3A(K)
W19(K) = X19(K) + Q19(K)
IF (W19(K) .GT. D19(K)) GO TO 46
IF (W19(K) .LT. D19(K)) D19(K) = W19(K)
46 IF (MK .LT. 1) W13(MK)=X13(1)+Q130
IF (MK .LT. 1) W14(MK)=X14(1)+Q140
IF (W13(MK) .GE. XM13) D19(K)=0.
IF (W14(MK) .GE. XM14) D19(K)=0.
X19(L) = X19(K) - D19(K) + Q19(K)
D20(K) = S20*U3(K)
Q20(K) = 0.35*(D21(MN)+D35(MN)+D37(MN))
IF (K .LE. 11) Q20(K) = Q200
W20(K) = X20(K) + Q20(K)
IF (W20(K) .GT. D20(K)) GO TO 48
IF (W20(K) .LT. D20(K)) D20(K) = W20(K)
48 X20(L) = X20(K) - D20(K) + Q20(K)
D21(K) = S21*U3(K)
Q21(K) = 0.24*Q20(K)/0.35
IF (K .LE. 11) Q21(K) = Q210
W21(K) = X21(K) + Q21(K)
IF (W21(K) .GT. D21(K)) GO TO 50
IF (W21(K) .LT. D21(K)) D21(K) = W21(K)
50 IF (MK .LT. 1) W13(MK)=X13(1)+Q130
IF (MK .LT. 1) W14(MK)=X14(1)+Q140
IF (W13(MK) .GE. XM13) D21(K)=0.
IF (W14(MK) .GE. XM14) D21(K)=0.
X21(L) = X21(K) + Q21(K) - D21(K)
D22(K) = S22*U3A(K)
Q22(K) = 0.41*Q20(K)/0.35
IF (K .LE. 11) Q22(K) = Q220
W22(K) = X22(K) + Q22(K)
IF (W22(K) .GT. D22(K)) GO TO 52
IF (W22(K) .LT. D22(K)) D22(K) = W22(K)
52 X22(L) = X22(K) - D22(K) + Q22(K)
D23(K) = S23*(ALP3 - U3(K) - U3A(K) - DEL3)
Q23(K) = .640*(D42(KL) + D43(KL))
IF (K .LE. 5) Q23(K)=Q230
W23(K) = X23(K) + Q23(K)
IF (W23(K) .GT. D23(K)) GO TO 54
IF (W23(K) .LT. D23(K)) D23(K) = W23(K)
54 IF (MK .LT. 1) W13(MK)=X13(1)+Q130
IF (MK .LT. 1) W14(MK)=X14(1)+Q140
IF (W13(MK) .GE. XM13) D23(K)=0.
IF (W14(MK) .GE. XM14) D23(K)=0.
X23(L) = X23(K) - D23(K) + Q23(K)
D24(K) = S24*(ALP3 - U3(K) - U3A(K) - DEL3)
Q24(K) = .290*Q23(K)/.640
IF (K .LE. 5) Q24(K)=Q240
W24(K) = X24(K) + Q24(K)
IF (W24(K) .GT. D24(K)) GO TO 56
IF (W24(K) .LT. D24(K)) D24(K) = W24(K)
56 X24(L) = X24(K) + Q24(K) - D24(K)
D25(K) = S25*DEL3
Q25(K) = .07*Q23(K)/.640

```

Figure C-2. Continued.

```

IF (K .LE. 5) Q25(K)=Q250
W25(K) = X25(K) + Q25(K)
IF (W25(K) .GT. D25(K)) GO TO 58
IF (W25(K) .LT. D25(K)) D25(K) = W25(K)
58 X25(L) = X25(K) - D25(K) + Q25(K)
D26(K) = S26*(ALP3 - U3(K) - U3A(K) - DEL3)
Q26(K) = 0.76*(D11(MM)+D16(MM))
IF (K .LE. 2) Q26(K) = Q260
W26(K) = X26(K) + Q26(K)
IF (W26(K) .GT. D26(K)) GO TO 60
IF (W26(K) .LT. D26(K)) D26(K) = W26(K)
60 X26(L) = X26(K) - D26(K) + Q26(K)
D27(K) = S27*(ALP3 - U3(K) - U3A(K) - DEL3)
Q27(K) = 0.03*Q26(K)/0.76
IF (K .LE. 2) Q27(K) = Q270
W27(K) = X27(K) + Q27(K)
IF (W27(K) .GT. D27(K)) GO TO 62
IF (W27(K) .LT. D27(K)) D27(K) = W27(K)
62 X27(L) = X27(K) + Q27(K) - D27(K)
D28(K) = S28*DEL3
Q28(K) = .210*Q26(K)/.760
IF (K .LE. 2) Q28(K) = Q280
W28(K) = X28(K) + Q28(K)
IF (W28(K) .GT. D28(K)) GO TO 64
IF (W28(K) .LT. D28(K)) D28(K) = W28(K)
64 X28(L) = X28(K) + Q28(K) - D28(K)

C
C *** INTERSECTION 461 DORR-RICHARDS
C
D29(K) = S29*U4(K)
Q29(K) = 0.900*(D17(MM) + D24(MM) + D28(MM))
IF (K .LE. 11) Q29(K) = Q290
W29(K) = X29(K) + Q29(K)
IF (W29(K) .GT. D29(K)) GO TO 66
IF (W29(K) .LT. D29(K)) D29(K) = W29(K)
66 X29(L) = X29(K) - D29(K) + Q29(K)
D30(K) = S30*U4(K)
Q30(K) = .05*Q29(K)/0.900
IF (K .LE. 11) Q30(K)=Q300
W30(K) = X30(K) + Q30(K)
IF (W30(K) .GT. D30(K)) GO TO 68
IF (W30(K) .LT. D30(K)) D30(K) = W30(K)
68 X30(L) = X30(K) - D30(K) + Q30(K)
D31(K) = S31*U4(K)
Q31(K) = 0.71*(D63(KM)+D60(KM))
IF (K .LE. 7) Q31(K) = Q310
W31(K) = X31(K) + Q31(K)
IF (W31(K) .GT. D31(K)) GO TO 70
IF (W31(K) .LT. D31(K)) D31(K) = W31(K)
70 X31(L) = X31(K) - D31(K) + Q31(K)
D32(K) = S32*U4(K)
Q32(K) = 0.27*Q31(K)/0.71
IF (K .LE. 7) Q32(K) = Q320
W32(K) = X32(K) + Q32(K)

```

Figure C-2. Continued.

```

      IF (W32(K) .GT. D32(K)) GO TO 72
      IF (W32(K) .LT. D32(K)) D32(K) = W32(K)
72  X32(L) = X32(K) - D32(K) + Q32(K)
      D33(K) = S33*(ALP4 - U4(K) - DEL4)
      Q33(K) = .30*(.59*(D95(JJ)+D97(JJ)+D47(JL)+D54(JL)+D58(JL)))
      IF (K .LE. 20) Q33(K) = Q330
      W33(K) = X33(K) + Q33(K)
      IF (W33(K) .GT. D33(K)) GO TO 74
      IF (W33(K) .LT. D33(K)) D33(K) = W33(K)
74  X33(L) = X33(K) + Q33(K) - D33(K)
      D34(K) = S34*(ALP4 - U4(K) - DEL4)
      Q34(K) = .30*(.22*(D95(JJ)+D97(JJ)+D47(JL)+D54(JL)+D58(JL)))
      IF (K .LE. 20) Q34(K) = Q340
      W34(K) = X34(K) + Q34(K)
      IF (W34(K) .GT. D34(K)) GO TO 76
      IF (W34(K) .LT. D34(K)) D34(K) = W34(K)
76  X34(L) = X34(K) - D34(K) + Q34(K)
      D35(K) = S35*DEL4
      Q35(K) = .30*(.19*(D95(JJ)+D97(JJ)+D47(JL)+D54(JL)+D58(JL)))
      IF (K .LE. 20) Q35(K) = Q350
      W35(K) = X35(K) + Q35(K)
      IF (W35(K) .GT. D35(K)) GO TO 78
      IF (W35(K) .LT. D35(K)) D35(K) = W35(K)
78  X35(L) = X35(K) - D35(K) + Q35(K)
      D36(K) = S36*(ALP4 - U4(K) - DEL4)
      W36(K) = X36(K) + Q36(K)
      IF (W36(K) .GT. D36(K)) GO TO 80
      IF (W36(K) .LT. D36(K)) D36(K) = W36(K)
80  X36(L) = X36(K) + Q36(K) - D36(K)
      D37(K) = S37*(ALP4 - U4(K) - DEL4)
      W37(K) = X37(K) + Q37(K)
      IF (W37(K) .GT. D37(K)) GO TO 82
      IF (W37(K) .LT. D37(K)) D37(K) = W37(K)
82  X37(L) = X37(K) - D37(K) + Q37(K)
      D38(K) = S38*DEL4
      W38(K) = X38(K) + Q38(K)
      IF (W38(K) .GT. D38(K)) GO TO 84
      IF (W38(K) .LT. D38(K)) D38(K) = W38(K)
84  X38(L) = X38(K) - D38(K) + Q38(K)
C
C *** INTERSECTION 587 REYNOLDS-NEBRASKA
C
      D39(K) = S39*(ALP5 - U5(K))
      W39(K) = X39(K) + Q39(K)
      IF (W39(K) .GT. D39(K)) GO TO 86
      IF (W39(K) .LT. D39(K)) D39(K) = W39(K)
86  X39(L) = X39(K) + Q39(K) - D39(K)
      D40(K) = S40*(ALP5 - U5(K))
      W40(K) = X40(K) + Q40(K)
      IF (W40(K) .GT. D40(K)) GO TO 88
      IF (W40(K) .LT. D40(K)) D40(K) = W40(K)
88  X40(L) = X40(K) + Q40(K) - D40(K)
      D41(K) = S41*(ALP5 - U5(K))
      W41(K) = X41(K) + Q41(K)

```

Figure C-2. Continued.



```

      IF (W41(K) .GT. D41(K)) GO TO 90
      IF (W41(K) .LT. D41(K)) D41(K) = W41(K)
90  X41(L) = X41(K) + Q41(K) - D41(K)
      D42(K) = S42*(ALP5 - U5(K))
      W42(K) = X42(K) + Q42(K)
      IF (W42(K) .GT. D42(K)) GO TO 92
      IF (W42(K) .LT. D42(K)) D42(K) = W42(K)
92  X42(L) = X42(K) + Q42(K) - D42(K)
      D43(K) = S43*U5(K)
      Q43(K) = 0.90*(D53(KL)+D49(KL)+D51(KL))
      IF (K .LE. 5) Q43(K) = Q430
      W43(K) = X43(K) + Q43(K)
      IF (W43(K) .GT. D43(K)) GO TO 94
      IF (W43(K) .LT. D43(K)) D43(K) = W43(K)
94  X43(L) = X43(K) + Q43(K) - D43(K)
      D44(K) = S44*DEL5
      Q44(K) = 0.10*Q43(K)/0.90
      IF (K .LE. 5) Q44(K) = Q440
      W44(K) = X44(K) + Q44(K)
      IF (W44(K) .GT. D44(K)) GO TO 96
      IF (W44(K) .LT. D44(K)) D44(K) = W44(K)
96  X44(L) = X44(K) + Q44(K) - D44(K)
      D45(K) = S45*(U5(K) - DEL5)
      Q45(K) = .900*(D26(KL) + D22(KL) + D18(KL))
      IF (K .LE. 5) Q45(K) = Q450
      W45(K) = X45(K) + Q45(K)
      IF (W45(K) .GT. D45(K)) GO TO 98
      IF (W45(K) .LT. D45(K)) D45(K) = W45(K)
98  X45(L) = X45(K) - D45(K) + Q45(K)
      D46(K) = S46*(U5(K) - DEL5)
      Q46(K) = .100*Q45(K)/.900
      IF (K .LE. 5) Q46(K) = Q460
      W46(K) = X46(K) + Q46(K)
      IF (W46(K) .GT. D46(K)) GO TO 100
      IF (W46(K) .LT. D46(K)) D46(K) = W46(K)
100 X46(L) = X46(K) - D46(K) + Q46(K)

C
C *** INTERSECTION 499 REYNOLDS-HILL
C
      D47(K) = S47*(ALP6 - U6(K) - U6A(K) - DEL6)
      W47(K) = X47(K) + Q47(K)
      IF (W47(K) .GT. D47(K)) GO TO 102
      IF (W47(K) .LT. D47(K)) D47(K) = W47(K)
102 X47(L) = X47(K) - D47(K) + Q47(K)
      D48(K) = S48*(ALP6 - U6(K) - U6A(K) - DEL6)
      W48(K) = X48(K) + Q48(K)
      IF (W48(K) .GT. D48(K)) GO TO 104
      IF (W48(K) .LT. D48(K)) D48(K) = W48(K)
104 X48(L) = X48(K) - D48(K) + Q48(K)
      D49(K) = S49*DEL6
      W49(K) = X49(K) + Q49(K)
      IF (W49(K) .GT. D49(K)) GO TO 106
      IF (W49(K) .LT. D49(K)) D49(K) = W49(K)
106 X49(L) = X49(K) + Q49(K) - D49(K)

```

Figure C-2. Continued.

```

D50(K) = S50*(ALP6 - U6(K) - U6A(K) - DEL6)
Q50(K) = .45*(.30*(D30(JL)+D36(JL))+.70*(D95(JK)+D97(JK)))
IF (K .LE. 20) Q50(K) = Q500
W50(K) = X50(K) + Q50(K)
IF (W50(K) .GT. D50(K)) GO TO 108
IF (W50(K) .LT. D50(K)) D50(K) = W50(K)
108 X50(L) = X50(K) - D50(K) + Q50(K)
D51(K) = S51*(ALP6 - U6(K) - U6A(K) - DEL6)
Q51(K) = .23*Q50(K)/.45
IF (K .LE. 20) Q51(K) = Q510
W51(K) = X51(K) + Q51(K)
IF (W51(K) .GT. D51(K)) GO TO 110
IF (W51(K) .LT. D51(K)) D51(K) = W51(K)
110 X51(L) = X51(K) - D51(K) + Q51(K)
D52(K) = S52*DEL6
Q52(K) = .32*Q50(K)/.45
IF (K .LE. 20) Q52(K) = Q520
W52(K) = X52(K) + Q52(K)
IF (W52(K) .GT. D52(K)) GO TO 112
IF (W52(K) .LT. D52(K)) D52(K) = W52(K)
112 X52(L) = X52(K) + Q52(K) - D52(K)
D53(K) = S53*U6(K)
W53(K) = X53(K) + Q53(K)
IF (W53(K) .GT. D53(K)) GO TO 114
IF (W53(K) .LT. D53(K)) D53(K) = W53(K)
114 X53(L) = X53(K) - D53(K) + Q53(K)
D54(K) = S54*U6(K)
W54(K) = X54(K) + Q54(K)
IF (W54(K) .GT. D54(K)) GO TO 116
IF (W54(K) .LT. D54(K)) D54(K) = W54(K)
116 X54(L) = X54(K) - D54(K) + Q54(K)
D55(K) = S55*U6A(K)
W55(K) = X55(K) + Q55(K)
IF (W55(K) .GT. D55(K)) GO TO 118
IF (W55(K) .LT. D55(K)) D55(K) = W55(K)
118 X55(L) = X55(K) + Q55(K) - D55(K)
D56(K) = S56*U6(K)
Q56(K) = .730*(D45(KL)+D40(KL))
IF (K .LE. 5) Q56(K) = Q560
W56(K) = X56(K) + Q56(K)
IF (W56(K) .GT. D56(K)) GO TO 120
IF (W56(K) .LT. D56(K)) D56(K) = W56(K)
120 X56(L) = X56(K) + Q56(K) - D56(K)
D57(K) = S57*U6(K)
Q57(K) = .04*Q56(K)/.730
IF (K .LE. 5) Q57(K) = Q570
W57(K) = X57(K) + Q57(K)
IF (W57(K) .GT. D57(K)) GO TO 122
IF (W57(K) .LT. D57(K)) D57(K) = W57(K)
122 X57(L) = X57(K) + Q57(K) - D57(K)
D58(K) = S58*U6A(K)
Q58(K) = .230*Q56(K)/.730
IF (K .LE. 5) Q58(K) = Q580
W58(K) = X58(K) + Q58(K)

```

Figure C-2. Continued.

```

      IF (W58(K) .GT. D58(K)) GO TO 124
      IF (W58(K) .LT. D58(K)) D58(K) = W58(K)
124  X58(L) = X58(K) + Q58(K) - D58(K)
C
C *** INTERSECTION 478 BYRNE-DORA
C
      D59(K) = S59*U7A(K)
      Q59(K) = .77*(D77(KL)+D79(KL))
      IF (K .LE. 5) Q59(K) = Q590
      W59(K) = X59(K) + Q59(K)
      IF (W59(K) .GT. D59(K)) GO TO 126
      IF (W59(K) .LT. D59(K)) D59(K) = W59(K)
126  IF (MK .LT. 1) W65(MK)=X65(1)+Q650
      IF (MK .LT. 1) W66(MK)=X66(1)+Q660
      IF (MK .LT. 1) W67(MK)=X67(1)+Q670
      IF (W65(MK) .GE. XM65) D59(K)=0.
      IF (W66(MK) .GE. XM66) D59(K)=0.
      IF (W67(MK) .GE. XM67) D59(K)=0.
      X59(L) = X59(K) - D59(K) + Q59(K)
      D60(K) = S60*U7(K)
      Q60(K) = .23*Q59(K)/.77
      IF (K .LE. 5) Q60(K) = Q600
      W60(K) = X60(K) + Q60(K)
      IF (W60(K) .GT. D60(K)) GO TO 128
      IF (W60(K) .LT. D60(K)) D60(K) = W60(K)
128  X60(L) = X60(K) - D60(K) + Q60(K)
      D61(K) = S61*(ALP7 - U7(K) - U7A(K))
      Q61(K) = 0.80*(D29(KM) + D34(KM) + D38(KM))
      IF (K .LE. 7) Q61(K) = Q610
      W61(K) = X61(K) + Q61(K)
      IF (W61(K) .GT. D61(K)) GO TO 130
      IF (W61(K) .LT. D61(K)) D61(K) = W61(K)
130  IF (MK .LT. 1) W65(MK)=X65(1)+Q650
      IF (MK .LT. 1) W66(MK)=X66(1)+Q660
      IF (MK .LT. 1) W67(MK)=X67(1)+Q670
      IF (W65(MK) .GE. XM65) D61(K)=0.
      IF (W66(MK) .GE. XM66) D61(K)=0.
      IF (W67(MK) .GE. XM67) D61(K)=0.
      X61(L) = X61(K) - D61(K) + Q61(K)
      D62(K) = S62*(ALP7 - U7(K) - U7A(K))
      Q62(K) = .20*Q61(K)/0.80
      IF (K .LE. 7) Q62(K) = Q620
      W62(K) = X62(K) + Q62(K)
      IF (W62(K) .GT. D62(K)) GO TO 132
      IF (W62(K) .LT. D62(K)) D62(K) = W62(K)
132  X62(L) = X62(K) - D62(K) + Q62(K)
      D63(K) = S63*(ALP7 - U7(K) - U7A(K))
      Q63(K) = 0.420*(D68(KN)+D71(KN))
      IF (K .LE. 3) Q63(K) = Q630
      W63(K) = X63(K) + Q63(K)
      IF (W63(K) .GT. D63(K)) GO TO 134
      IF (W63(K) .LT. D63(K)) D63(K) = W63(K)
134  X63(L) = X63(K) + Q63(K) - D63(K)
      D64(K) = S64*U7A(K)

```

Figure C-2. Continued.

```

      IF (W58(K) .GT. D58(K)) GO TO 124
      IF (W58(K) .LT. D58(K)) D58(K) = W58(K)
124  X58(L) = X58(K) + Q58(K) - D58(K)
C
C *** INTERSECTION 478 BYRNE-DORR
C
      D59(K) = S59*U7A(K)
      Q59(K) = .77*(D77(KL)+D79(KL))
      IF (K .LE. 5) Q59(K) = Q590
      W59(K) = X59(K) + Q59(K)
      IF (W59(K) .GT. D59(K)) GO TO 126
      IF (W59(K) .LT. D59(K)) D59(K) = W59(K)
126  IF (MK .LT. 1) W65(MK)=X65(1)+Q650
      IF (MK .LT. 1) W66(MK)=X66(1)+Q660
      IF (MK .LT. 1) W67(MK)=X67(1)+Q670
      IF (W65(MK) .GE. XM65) D59(K)=0.
      IF (W66(MK) .GE. XM66) D59(K)=0.
      IF (W67(MK) .GE. XM67) D59(K)=0.
      X59(L) = X59(K) - D59(K) + Q59(K)
      D60(K) = S60*U7(K)
      Q60(K) = .23*Q59(K)/.77
      IF (K .LE. 5) Q60(K) = Q600
      W60(K) = X60(K) + Q60(K)
      IF (W60(K) .GT. D60(K)) GO TO 128
      IF (W60(K) .LT. D60(K)) D60(K) = W60(K)
128  X60(L) = X60(K) - D60(K) + Q60(K)
      D61(K) = S61*(ALP7 - U7(K) - U7A(K))
      Q61(K) = 0.80*(D29(KM) + D34(KM) + D38(KM))
      IF (K .LE. 7) Q61(K) = Q610
      W61(K) = X61(K) + Q61(K)
      IF (W61(K) .GT. D61(K)) GO TO 130
      IF (W61(K) .LT. D61(K)) D61(K) = W61(K)
130  IF (MK .LT. 1) W65(MK)=X65(1)+Q650
      IF (MK .LT. 1) W66(MK)=X66(1)+Q660
      IF (MK .LT. 1) W67(MK)=X67(1)+Q670
      IF (W65(MK) .GE. XM65) D61(K)=0.
      IF (W66(MK) .GE. XM66) D61(K)=0.
      IF (W67(MK) .GE. XM67) D61(K)=0.
      X61(L) = X61(K) - D61(K) + Q61(K)
      D62(K) = S62*(ALP7 - U7(K) - U7A(K))
      Q62(K) = .20*Q61(K)/0.80
      IF (K .LE. 7) Q62(K) = Q620
      W62(K) = X62(K) + Q62(K)
      IF (W62(K) .GT. D62(K)) GO TO 132
      IF (W62(K) .LT. D62(K)) D62(K) = W62(K)
132  X62(L) = X62(K) - D62(K) + Q62(K)
      D63(K) = S63*(ALP7 - U7(K) - U7A(K))
      Q63(K) = 0.420*(D68(KN)+D71(KN))
      IF (K .LE. 3) Q63(K) = Q630
      W63(K) = X63(K) + Q63(K)
      IF (W63(K) .GT. D63(K)) GO TO 134
      IF (W63(K) .LT. D63(K)) D63(K) = W63(K)
134  X63(L) = X63(K) + Q63(K) - D63(K)
      D64(K) = S64*U7A(K)

```

Figure C-2. Continued.

```

Q64(K) = 0.580*Q63(K)/0.420
IF (K .LE. 3) Q64(K) = Q640
W64(K) = X64(K) + Q64(K)
IF (W64(K) .GT. D64(K)) GO TO 136
IF (W64(K) .LT. D64(K)) D64(K) = W64(K)
136 X64(L) = X64(K) - D64(K) + Q64(K)
C
C *** INTERSECTION 497 DORR-SECOR
C
D65(K) = S65*U8(K)
Q65(K) = 0.436*(D61(KN)+D59(KN))
IF (K .LE. 3) Q65(K) = Q650
W65(K) = X65(K) + Q65(K)
IF (W65(K) .GT. D65(K)) GO TO 138
IF (W65(K) .LT. D65(K)) D65(K) = W65(K)
138 X65(L) = X65(K) - D65(K) + Q65(K)
D66(K) = S66*U8(K)
Q66(K) = 0.004*Q65(K)/0.436
IF (K .LE. 3) Q66(K) = Q660
W66(K) = X66(K) + Q66(K)
IF (W66(K) .GT. D66(K)) GO TO 140
IF (W66(K) .LT. D66(K)) D66(K) = W66(K)
140 X66(L) = X66(K) + Q66(K) - D66(K)
D67(K) = S67*U8A(K)
Q67(K) = 0.56*Q65(K)/0.436
IF (K .LE. 3) Q67(K) = Q670
W67(K) = X67(K) + Q67(K)
IF (W67(K) .GT. D67(K)) GO TO 142
IF (W67(K) .LT. D67(K)) D67(K) = W67(K)
142 X67(L) = X67(K) - D67(K) + Q67(K)
D68(K) = S68*U8(K)
W68(K) = X68(K) + Q68(K)
IF (W68(K) .GT. D68(K)) GO TO 144
IF (W68(K) .LT. D68(K)) D68(K) = W68(K)
144 IF (MK .LT. 1) W63(MK)=X63(1)+Q630
IF (MK .LT. 1) W64(MK)=X64(1)+Q640
IF (W63(MK) .GE. XM63) D68(K)=0.
IF (W64(MK) .GE. XM64) D68(K)=0.
X68(L) = X68(K) - D68(K) + Q68(K)
D69(K) = S69*U8(K)
W69(K) = X69(K) + Q69(K)
IF (W69(K) .GT. D69(K)) GO TO 146
IF (W69(K) .LT. D69(K)) D69(K) = W69(K)
146 X69(L) = X69(K) + Q69(K) - D69(K)
D70(K) = S70*(ALPB - U8(K) - U8A(K))
W70(K) = X70(K) + Q70(K)
IF (W70(K) .GT. D70(K)) GO TO 148
IF (W70(K) .LT. D70(K)) D70(K) = W70(K)
148 X70(L) = X70(K) + Q70(K) - D70(K)
D71(K) = S71*U8A(K)
W71(K) = X71(K) + Q71(K)
IF (W71(K) .GT. D71(K)) GO TO 150
IF (W71(K) .LT. D71(K)) D71(K) = W71(K)
150 IF (MK .LT. 1) W63(MK)=X63(1)+Q630

```

Figure C-2. Continued.

```

IF (MK .LT. 1) W64(MK)=X64(1)+Q640
IF (W63(MK) .GE. XM63) D71(K)=0.
IF (W64(MK) .GE. XM64) D71(K)=0.
X71(L) = X71(K) + Q71(K) - D71(K)
D72(K) = S72*DEL8
W72(K) = X72(K) + Q72(K)
IF (W72(K) .GT. D72(K)) GO TO 152
IF (W72(K) .LT. D72(K)) D72(K) = W72(K)
152 X72(L) = X72(K) + Q72(K) - D72(K)
D73(K) = S73*(ALP8 - U8(K) - U8A(K) - DEL8)
W73(K) = X73(K) + Q73(K)
IF (W73(K) .GT. D73(K)) GO TO 154
IF (W73(K) .LT. D73(K)) D73(K) = W73(K)
154 X73(L) = X73(K) + Q73(K) - D73(K)
D74(K) = S74*(ALP8 - U8(K) - U8A(K) - DEL8)
W74(K) = X74(K) + Q74(K)
IF (W74(K) .GT. D74(K)) GO TO 156
IF (W74(K) .LT. D74(K)) D74(K) = W74(K)
156 X74(L) = X74(K) + Q74(K) - D74(K)
C
C *** INTERSECTION 525 BYRNE-NEBRASKA
C
D75(K) = S75*U9(K)
Q75(K) = .85*(D62(KL) + D64(KL))
IF (K .LE. 5) Q75(K)=Q750
W75(K) = X75(K) + Q75(K)
IF (W75(K) .GT. D75(K)) GO TO 158
IF (W75(K) .LT. D75(K)) D75(K) = W75(K)
158 X75(L) = X75(K) - D75(K) + Q75(K)
D76(K) = S76*DEL9
Q76(K) = .15*Q75(K)/.85
IF (K .LE. 5) Q76(K)=Q760
W76(K) = X76(K) + Q76(K)
IF (W76(K) .GT. D76(K)) GO TO 160
IF (W76(K) .LT. D76(K)) D76(K) = W76(K)
160 X76(L) = X76(K) - D76(K) + Q76(K)
D77(K) = S77*(U9(K) - DEL9)
Q77(K) = .78*(D83(KL)+D85(KL)+D87(KL))
IF (K .LE. 5) Q77(K) = Q770
W77(K) = X77(K) + Q77(K)
IF (W77(K) .GT. D77(K)) GO TO 162
IF (W77(K) .LT. D77(K)) D77(K) = W77(K)
162 X77(L) = X77(K) - D77(K) + Q77(K)
D78(K) = S78*(U9(K) - DEL9)
Q78(K) = .22*Q77(K)/.78
IF (K .LE. 5) Q78(K) = Q780
W78(K) = X78(K) + Q78(K)
IF (W78(K) .GT. D78(K)) GO TO 164
IF (W78(K) .LT. D78(K)) D78(K) = W78(K)
164 X78(L) = X78(K) - D78(K) + Q78(K)
D79(K) = S79*(ALP9 - U9(K))
W79(K) = X79(K) + Q79(K)
IF (W79(K) .GT. D79(K)) GO TO 166
IF (W79(K) .LT. D79(K)) D79(K) = W79(K)

```

Figure C-2. Continued.

```

166 X79(L) = X79(K) + Q79(K) - D79(K)
    D80(K) = S80*(ALP9 - U9(K))
    W80(K) = X80(K) + Q80(K)
    IF (W80(K) .GT. D80(K)) GO TO 168
    IF (W80(K) .LT. D80(K)) D80(K) = W80(K)
168 X80(L) = X80(K) - D80(K) + Q80(K)
C
C *** INTERSECTION 477 BYRNE-HILL
C
    D81(K) = S81*(ALP10 - U10(K) - U10A(K) - DEL10)
    Q81(K) = .70*(D93(M)+D98(M))
    IF (M .LE. 4) Q81(K) = Q810
    W81(K) = X81(K) + Q81(K)
    IF (W81(K) .GT. D81(K)) GO TO 170
    IF (W81(K) .LT. D81(K)) D81(K) = W81(K)
170 X81(L) = X81(K) - D81(K) + Q81(K)
    D82(K) = S82*(ALP10 - U10(K) - U10A(K) - DEL10)
    Q82(K) = .20*Q81(K)/.70
    IF (K .LE. 4) Q82(K) = Q820
    W82(K) = X82(K) + Q82(K)
    IF (W82(K) .GT. D82(K)) GO TO 172
    IF (W82(K) .LT. D82(K)) D82(K) = W82(K)
172 X82(L) = X82(K) + Q82(K) - D82(K)
    D83(K) = S83*DEL10
    Q83(K) = .10*Q81(K)/.70
    IF (K .LE. 4) Q83(K) = Q830
    W83(K) = X83(K) + Q83(K)
    IF (W83(K) .GT. D83(K)) GO TO 174
    IF (W83(K) .LT. D83(K)) D83(K) = W83(K)
174 X83(L) = X83(K) - D83(K) + Q83(K)
    D84(K) = S84*(ALP10 - U10(K) - U10A(K) - DEL10)
    W84(K) = X84(K) + Q84(K)
    IF (W84(K) .GT. D84(K)) GO TO 176
    IF (W84(K) .LT. D84(K)) D84(K) = W84(K)
176 X84(L) = X84(K) - D84(K) + Q84(K)
    D85(K) = S85*(ALP10 - U10(K) - U10A(K) - DEL10)
    W85(K) = X85(K) + Q85(K)
    IF (W85(K) .GT. D85(K)) GO TO 178
    IF (W85(K) .LT. D85(K)) D85(K) = W85(K)
178 X85(L) = X85(K) + Q85(K) - D85(K)
    D86(K) = S86*DEL10
    W86(K) = X86(K) + Q86(K)
    IF (W86(K) .GT. D86(K)) GO TO 180
    IF (W86(K) .LT. D86(K)) D86(K) = W86(K)
180 X86(L) = X86(K) + Q86(K) - D86(K)
    D87(K) = S87*U10(K)
    W87(K) = X87(K) + Q87(K)
    IF (W87(K) .GT. D87(K)) GO TO 182
    IF (W87(K) .LT. D87(K)) D87(K) = W87(K)
182 X87(L) = X87(K) + Q87(K) - D87(K)
    D88(K) = S88*U10(K)
    W88(K) = X88(K) + Q88(K)
    IF (W88(K) .GT. D88(K)) GO TO 184
    IF (W88(K) .LT. D88(K)) D88(K) = W88(K)

```

Figure C-2. Continued.

```

184 X88(L) = X88(K) + Q88(K) - D88(K)
    D89(K) = S89*U10A(K)
    W89(K) = X89(K) + Q89(K)
    IF (W89(K) .GT. D89(K)) GO TO 186
    IF (W89(K) .LT. D89(K)) D89(K) = W89(K)
186 X89(L) = X89(K) + Q89(K) - D89(K)
    D90(K) = S90*U10(K)
    Q90(K) = 0.79*(D75(KL)+D80(KL))
    IF (K .LE. 5) Q90(K) = Q900
    W90(K) = X90(K) + Q90(K)
    IF (W90(K) .GT. D90(K)) GO TO 187
    IF (W90(K) .LT. D90(K)) D90(K) = W90(K)
187 X90(L) = X90(K) - D90(K) + Q90(K)
    D91(K) = S91*U10(K)
    Q91(K) = 0.07*Q90(K)/0.79
    IF (K .LE. 5) Q91(K) = Q910
    W91(K) = X91(K) + Q91(K)
    IF (W91(K) .GT. D91(K)) GO TO 188
    IF (W91(K) .LT. D91(K)) D91(K) = W91(K)
188 X91(L) = X91(K) - D91(K) + Q91(K)
    D92(K) = S92*U10A(K)
    Q92(K) = 0.14*Q90(K)/0.79
    IF (K .LE. 5) Q92(K) = Q920
    W92(K) = X92(K) + Q92(K)
    IF (W92(K) .GT. D92(K)) GO TO 190
    IF (W92(K) .LT. D92(K)) D92(K) = W92(K)
190 X92(L) = X92(K) + Q92(K) - D92(K)
C
C *** INTERSECTION 581 HILL-KEYSER SCHOOL
C
    D93(K) = S93*U11(K)
    Q93(K) = 0.70*(0.70*(D47(JK)+D54(JK)+D58(JK)))
1+0.70*(0.70*(D30(JJ)+D36(JJ)))
    IF (K .LE. 15) Q93(K) = Q930
    W93(K) = X93(K) + Q93(K)
    IF (W93(K) .GT. D93(K)) GO TO 192
    IF (W93(K) .LT. D93(K)) D93(K) = W93(K)
192 X93(L) = X93(K) - D93(K) + Q93(K)
    D94(K) = S94*DEL11
    Q94(K) = 0.30*(0.70*(D47(JK)+D54(JK)+D58(JK)))
1+0.30*(0.70*(D30(JJ)+D36(JJ)))
    IF (K .LE. 15) Q94(K) = Q940
    W94(K) = X94(K) + Q94(K)
    IF (W94(K) .GT. D94(K)) GO TO 193
    IF (W94(K) .LT. D94(K)) D94(K) = W94(K)
193 X94(L) = X94(K) - D94(K) + Q94(K)
    D95(K) = S95*(U11(K) - DEL11)
    Q95(K) = 0.70*(D84(M)+D89(M)+D91(M))
    IF (K .LE. 4) Q95(K) = Q950
    W95(K) = X95(K) + Q95(K)
    IF (W95(K) .GT. D95(K)) GO TO 194
    IF (W95(K) .LT. D95(K)) D95(K) = W95(K)
194 X95(L) = X95(K) + Q95(K) - D95(K)
    D96(K) = S96*(U11(K) - DEL11)

```

Figure C-2. Continued.



```

Q96(K) = 0.30*Q95(K)/0.70
IF (K .LE. 4) Q96(K) = Q960
W96(K) = X96(K) + Q96(K)
IF (W96(K) .GT. D96(K)) GO TO 196
IF (W96(K) .LT. D96(K)) D96(K) = W96(K)
196 X96(L) = X96(K) + Q96(K) - D96(K)
D97(K) = S97*(ALP11 - U11(K))
W97(K) = X97(K) + Q97(K)
IF (W97(K) .GT. D97(K)) GO TO 197
IF (W97(K) .LT. D97(K)) D97(K) = W97(K)
197 X97(L) = X97(K) + Q97(K) - D97(K)
D98(K) = S98*(ALP11 - U11(K))
W98(K) = X98(K) + Q98(K)
IF (W98(K) .GT. D98(K)) GO TO 198
IF (W98(K) .LT. D98(K)) D98(K) = W98(K)
198 X98(L) = X98(K) + Q98(K) - D98(K)
200 CONTINUE
P=0.
DO 245 J=91,91
P1=W1(J)**2+W2(J)**2+W3(J)**2+W4(J)**2+W5(J)**2+W6(J)**2+W7(J)**2-
1+W8(J)**2+W9(J)**2+W10(J)**2+W11(J)**2+W12(J)**2+W13(J)**2 -
2+W14(J)**2+W15(J)**2+W16(J)**2+W17(J)**2+W18(J)**2+W19(J)**2 -
3+W20(J)**2+W21(J)**2+W22(J)**2+W23(J)**2+W24(J)**2+W25(J)**2 -
4+W26(J)**2+W27(J)**2+W28(J)**2+W29(J)**2+W30(J)**2+W31(J)**2 -
5+W32(J)**2+W33(J)**2+W34(J)**2+W35(J)**2+W36(J)**2+W37(J)**2 -
6+W38(J)**2+W39(J)**2+W40(J)**2+W41(J)**2+W42(J)**2+W43(J)**2 -
7+W44(J)**2+W45(J)**2+W46(J)**2+W47(J)**2+W48(J)**2+W49(J)**2 -
8+W50(J)**2+W51(J)**2+W52(J)**2
P=P+P1
245 CONTINUE
DO 250 J=91,91
P2=W53(J)**2+W54(J)**2+W55(J)**2+W56(J)**2+W57(J)**2+W58(J)**2 -
1+W59(J)**2+W60(J)**2+W61(J)**2+W62(J)**2+W63(J)**2+W64(J)**2 -
3+W65(J)**2+W66(J)**2+W67(J)**2+W68(J)**2+W69(J)**2+W70(J)**2 -
4+W71(J)**2+W72(J)**2+W73(J)**2+W74(J)**2+W75(J)**2+W76(J)**2 -
5+W77(J)**2+W78(J)**2+W79(J)**2+W80(J)**2+W81(J)**2+W82(J)**2 -
6+W83(J)**2+W84(J)**2+W85(J)**2+W86(J)**2+W87(J)**2+W88(J)**2 -
7+W89(J)**2+W90(J)**2+W91(J)**2+W92(J)**2+W93(J)**2+W94(J)**2 -
8+W95(J)**2+W96(J)**2+W97(J)**2+W98(J)**2
P=P+P2
250 CONTINUE
DO 260 J=91,91
P3=R1*((U1(J)-.0690)**2)+R2*((U2(J)-.0700)**2) -
1+R3*((U3(J)-.0290)**2)+R3A*((U3A(J)-.0200)**2) -
2+R4*((U4(J)-.0640)**2)+R5*((U5(J)-.0650)**2) -
3+R6*((U6(J)-.0450)**2)+R6A*((U6A(J)-.0150)**2) -
4+R7*((U7(J)-.0170)**2)+R7A*((U7A(J)-.0360)**2) -
5+R8*((U8(J)-.0240)**2)+R8A*((U8A(J)-.0380)**2) -
6+R9*((U9(J)-.0660)**2)+R10*((U10(J)-.0480)**2) -
7+R10A*((U10A(J)-.0100)**2)+R11*((U11(J)-.0660)**2)
P=P+P3
260 CONTINUE
P=P/98.
IF (P .LT. 1.000) P=P**.5

```

Figure C-2. Continued.

```
TMIN = P  
RETURN  
END
```

Figure C-2. Concluded.

# APPENDIX D - LISTING OF COMPUTER PROGRAMS - SECTION II

## C \*\*\* FUNCTION FOR OPTIMIZATION - SECTION II

DOUBLE PRECISION FUNCTION TMINA(U)

DOUBLE PRECISION U

DIMENSION U(16)

```

DIMENSION X1(92),X2(92),X3(92),X4(92),X5(92),X6(92),X7(92),
1X8(92),X9(92),X10(92),X11(92),X12(92),X13(92),X14(92),X15(92),
2X16(92),X17(92),X18(92),X19(92),X20(92),X21(92),X22(92),X23(92),
3X24(92),X25(92),X26(92),X27(92),X28(92),X29(92),X30(92),X31(92),
4X32(92),X33(92),X34(92),X35(92),X37(92),X38(92),X39(92),X40(92),
5X41(92),X42(92),X43(92),X44(92),X45(92),X46(92),X47(92),X48(92),
6X49(92),X50(92),X51(92),X52(92),X53(92),X53B(92),X54(92),X55(92),
7X56(92),X57(92),X58(92),X59(92),X60(92),X61(92),X62(92),X63(92),
8X64(92),X65(92),X66(92),X67(92),X68(92),X69(92),X70(92),X71(92),
9X72(92),X73(92),X74(92),X75(92),X76(92),X77(92),X78(92),X79(92),
AX80(92),X81(92),X82(92),X83(92),X84(92),X85(92),X86(92),X87(92),
BX88(93),X89(92),X90(92),X91(92),X92(92),X93(92),X94(92),X95(92),
CX96(92),X97(92),X98(92),X99(92),X100(92),X101(92),X102(92),
DX103(92),X104(92),X105(92),X106(92)
DIMENSION W1(92),W2(92),W3(92),W4(92),W5(92),W6(92),W7(92),
1W8(92),W9(92),W10(92),W11(92),W12(92),W13(92),W14(92),W15(92),
2W16(92),W17(92),W18(92),W19(92),W20(92),W21(92),W22(92),W23(92),
3W24(92),W25(92),W26(92),W27(92),W28(92),W29(92),W30(92),W31(92),
4W32(92),W33(92),W34(92),W35(92),W37(92),W38(92),W39(92),W40(92),
5W41(92),W42(92),W43(92),W44(92),W45(92),W46(92),W47(92),W48(92),
6W49(92),W50(92),W51(92),W52(92),W53(92),W53B(92),W54(92),W55(92),
7W56(92),W57(92),W58(92),W59(92),W60(92),W61(92),W62(92),W63(92),
8W64(92),W65(92),W66(92),W67(92),W68(92),W69(92),W70(92),W71(92),
9W72(92),W73(92),W74(92),W75(92),W76(92),W77(92),W78(92),W79(92),
AW80(92),W81(92),W82(92),W83(92),W84(92),W85(92),W86(92),W87(92),
BW88(93),W89(92),W90(92),W91(92),W92(92),W93(92),W94(92),W95(92),
CW96(92),W97(92),W98(92),W99(92),W100(92),W101(92),W102(92),
DW103(92),W104(92),W105(92),W106(92)
DIMENSION D1(92),D2(92),D3(92),D4(92),D5(92),D6(92),D7(92),
1D8(92),D9(92),D10(92),D11(92),D12(92),D13(92),D14(92),D15(92),
2D16(92),D17(92),D18(92),D19(92),D20(92),D21(92),D22(92),D23(92),
3D24(92),D25(92),D26(92),D27(92),D28(92),D29(92),D30(92),D31(92),
4D32(92),D33(92),D34(92),D35(92),D37(92),D38(92),D39(92),D40(92),
5D41(92),D42(92),D43(92),D44(92),D45(92),D46(92),D47(92),D48(92),
6D49(92),D50(92),D51(92),D52(92),D53(92),D53B(92),D54(92),D55(92),
7D56(92),D57(92),D58(92),D59(92),D60(92),D61(92),D62(92),D63(92),
8D64(92),D65(92),D66(92),D67(92),D68(92),D69(92),D70(92),D71(92),
9D72(92),D73(92),D74(92),D75(92),D76(92),D77(92),D78(92),D79(92),
AD80(92),D81(92),D82(92),D83(92),D84(92),D85(92),D86(92),D87(92),
BD88(93),D89(92),D90(92),D91(92),D92(92),D93(92),D94(92),D95(92),
CD96(92),D97(92),D98(92),D99(92),D100(92),D101(92),D102(92),
DD103(92),D104(92),D105(92),D106(92)
DIMENSION Q1(92),Q2(92),Q3(92),Q4(92),Q5(92),Q6(92),Q7(92),
1Q8(92),Q9(92),Q10(92),Q11(92),Q12(92),Q13(92),Q14(92),Q15(92),
2Q16(92),Q17(92),Q18(92),Q19(92),Q20(92),Q21(92),Q22(92),Q23(92),
3Q24(92),Q25(92),Q26(92),Q27(92),Q28(92),Q29(92),Q30(92),Q31(92),
4Q32(92),Q33(92),Q34(92),Q35(92),Q37(92),Q38(92),Q39(92),Q40(92),
5Q41(92),Q42(92),Q43(92),Q44(92),Q45(92),Q46(92),Q47(92),Q48(92),
6Q49(92),Q50(92),Q51(92),Q52(92),Q53(92),Q53B(92),Q54(92),Q55(92),
7Q56(92),Q57(92),Q58(92),Q59(92),Q60(92),Q61(92),Q62(92),Q63(92),

```

Figure D-1.

BQ64 (92), Q65 (92), Q66 (92), Q67 (92), Q68 (92), Q69 (92), Q70 (92), Q71 (92), -  
 9Q72 (92), Q73 (92), Q74 (92), Q75 (92), Q76 (92), Q77 (92), Q78 (92), Q79 (92), -  
 AQ80 (92), Q81 (92), Q82 (92), Q83 (92), Q84 (92), Q85 (92), Q86 (92), Q87 (92), -  
 BQ88 (93), Q89 (92), Q90 (92), Q91 (92), Q92 (92), Q93 (92), Q94 (92), Q95 (92), -  
 CQ96 (92), Q97 (92), Q98 (92), Q99 (92), Q100 (92), Q101 (92), Q102 (92), -  
 DQ103 (92), Q104 (92), Q105 (92), Q106 (92), U1 (92), U1A (92), U2 (92), U3 (92), -  
 EU3A (92), U4 (92), U4A (92), U5 (92), U6 (92), U6B (92), U7 (92), U8 (92), -  
 FU9 (92), U10 (92), U11 (92), U11A (92)  
 DATA X1 (1), X2 (1), X3 (1), X4 (1), X5 (1), X6 (1) / 20., 5., 5., 20., 5., 5. /  
 DATA X7 (1), X8 (1), X9 (1), X10 (1), X11 (1) / 20., 5., 5., 20., 5. /  
 DATA X12 (1), X13 (1), X14 (1), X15 (1), X16 (1) / 5., 20., 5., 20., 5. /  
 DATA X17 (1), X18 (1), X19 (1), X20 (1), X21 (1) / 10., 10., 20., 5., 5. /  
 DATA X22 (1), X23 (1), X24 (1), X25 (1), X26 (1) / 20., 5., 5., 20., 5. /  
 DATA X27 (1), X28 (1), X29 (1), X30 (1), X31 (1) / 5., 20., 5., 5., 20. /  
 DATA X32 (1), X33 (1), X34 (1), X35 (1) / 5., 5., 20., 5. /  
 DATA X37 (1), X38 (1), X39 (1), X40 (1), X41 (1) / 10., 5., 5., 10., 5. /  
 DATA X42 (1), X43 (1), X44 (1), X45 (1), X46 (1) / 5., 20., 5., 5., 20. /  
 DATA X47 (1), X48 (1), X49 (1), X50 (1), X51 (1) / 5., 5., 10., 5., 10. /  
 DATA X52 (1), X53 (1), X53B (1), X54 (1), X55 (1) / 5., 20., 6., 5., 20. /  
 DATA X56 (1), X57 (1), X58 (1), X59 (1), X60 (1) / 5., 3., 10., 5., 10. /  
 DATA X61 (1), X62 (1), X63 (1), X64 (1), X65 (1) / 10., 5., 5., 6., 20. /  
 DATA X66 (1), X67 (1), X68 (1), X69 (1), X70 (1) / 5., 20., 5., 20., 5. /  
 DATA X71 (1), X72 (1), X73 (1), X74 (1), X75 (1) / 20., 5., 5., 20., 5. /  
 DATA X76 (1), X77 (1), X78 (1), X79 (1), X80 (1) / 5., 10., 5., 5., 10. /  
 DATA X81 (1), X82 (1), X83 (1), X84 (1), X85 (1) / 5., 5., 10., 5., 20. /  
 DATA X86 (1), X87 (1), X88 (1), X89 (1), X90 (1) / 5., 10., 10., 20., 5. /  
 DATA X91 (1), X92 (1), X93 (1), X94 (1), X95 (1) / 20., 5., 10., 10., 20. /  
 DATA X96 (1), X97 (1), X98 (1), X99 (1), X100 (1) / 5., 5., 20., 5., 5. /  
 DATA X101 (1), X102 (1), X103 (1), X104 (1) / 20., 5., 5., 20. /  
 DATA X105 (1), X106 (1) / 5., 5. /  
 DATA XM31, XM32, XM33, XM46, XM47, XM48 / 20., 8., 8., 20., 8., 15. /  
 DATA XM53B, XM57, XM64 / 8., 4., 8. /  
 DATA S1, S2, S3, S4, S5, S6, S7 / 80., 25., 25., 80., 25., 25., 80. /  
 DATA S8, S9, S10, S11, S12, S13, S14 / 25., 25., 80., 25., 25., 80., 25. /  
 DATA S15, S16, S17, S18, S19, S20, S21 / 80., 25., 40., 40., 80., 25., 25. /  
 DATA S22, S23, S24, S25, S26, S27, S28 / 80., 25., 25., 80., 25., 25., 80. /  
 DATA S29, S30, S31, S32, S33, S34, S35 / 25., 25., 80., 25., 25., 80., 25. /  
 DATA S37, S38, S39, S40, S41, S42, S43 / 40., 25., 25., 40., 25., 25., 80. /  
 DATA S44, S45, S46, S47, S48, S49, S50 / 25., 25., 80., 25., 25., 40., 25. /  
 DATA S51, S52, S53, S53B, S54, S55, S56 / 40., 25., 80., 80., 25., 80., 25. /  
 DATA S57, S58, S59, S60, S61, S62, S63 / 25., 40., 25., 40., 40., 25., 25. /  
 DATA S64, S65, S66, S67, S68, S69, S70 / 80., 80., 25., 80., 25., 80., 25. /  
 DATA S71, S72, S73, S74, S75, S76, S77 / 80., 25., 25., 80., 25., 25., 40. /  
 DATA S78, S79, S80, S81, S82, S83, S84 / 25., 25., 40., 25., 25., 80., 25. /  
 DATA S85, S86, S87, S88, S89, S90, S91 / 80., 25., 40., 40., 80., 25., 80. /  
 DATA S92, S93, S94, S95, S96, S97, S98 / 25., 40., 40., 80., 25., 25., 80. /  
 DATA S99, S100, S101, S102, S103, S104 / 25., 25., 80., 25., 25., 80. /  
 DATA S105, S106 / 25., 25. /  
 DATA R1, R1A, R2, R3, R3A, R4 / 0., 0., 0., 0., 0., 0. /  
 DATA R4A, R5, R6, R6B, R7, R8 / 0., 0., 0., 0., 0., 0. /  
 DATA R9, R10, R11, R11A / 0., 0., 0., 0. /  
 TFR=10.  
 Q1 (1) = 6.97/TFR  
 Q2 (1) = 3.5/TFR

Figure D-1. Continued.

Q3(1) = 4.56/TFR  
 Q4(1) = 9.02/TFR  
 Q5(1) = 2.48/TFR  
 Q6(1) = 3.85/TFR  
 Q70A = 15.49/TFR  
 Q80A = 3.3/TFR  
 Q90A = 5.15/TFR  
 Q10(1) = 18.85/TFR  
 Q11(1) = 6.54/TFR  
 Q12(1) = 2.38/TFR  
 Q130 = 23.83/TFR  
 Q140 = 2.57/TFR  
 Q150 = 17.86/TFR  
 Q160 = 1.77/TFR  
 Q17(1) = 4.12/TFR  
 Q18(1) = 1.78/TFR  
 Q19(1) = 5.62/TFR  
 Q20(1) = 1.08/TFR  
 Q21(1) = 3.54/TFR  
 Q220 = 11.28/TFR  
 Q230 = 3.03/TFR  
 Q240 = 8.05/TFR  
 Q250 = 12.95/TFR  
 Q260 = 4.24/TFR  
 Q270 = 1.08/TFR  
 Q280 = 14.98/TFR  
 Q290 = 3.03/TFR  
 Q300 = 2.81/TFR  
 Q310 = 10.94/TFR  
 Q320 = .725/TFR  
 Q330 = 5.01/TFR  
 Q340 = 12.17/TFR  
 Q350 = 9.24/TFR  
 Q37(1) = 3.68/TFR  
 Q38(1) = 5.08/TFR  
 Q39(1) = 5.41/TFR  
 Q400 = 5.14/TFR  
 Q410 = .35/TFR  
 Q420 = 1.25/TFR  
 Q430 = 8.5/TFR  
 Q440 = .725/TFR  
 Q450 = .45/TFR  
 Q460 = 10.33/TFR  
 Q470 = 1.79/TFR  
 Q480 = 4.38/TFR  
 Q49(1) = .55/TFR  
 Q50(1) = .525/TFR  
 Q510 = .30/TFR  
 Q520 = 3.22/TFR  
 Q530 = 6.56/TFR  
 Q540 = .392/TFR  
 Q550 = 7.58/TFR  
 Q560 = .217/TFR  
 Q570 = 1.57/TFR

Figure D-1. Continued.

Q58(1) = .075/TFR  
Q59(1) = .175/TFR  
Q60(1) = .017/TFR  
Q610 = .35/TFR  
Q620 = 1.91/TFR  
Q630 = .475/TFR  
Q640 = 7.76/TFR  
Q650 = 6.35/TFR  
Q660 = .275/TFR  
Q67(1) = 4.1/TFR  
Q68(1) = 5.38/TFR  
Q690 = 4.23/TFR  
Q700 = 2.57/TFR  
Q710 = 5.06/TFR  
Q720 = 1.45/TFR  
Q730 = .723/TFR  
Q740 = 3.06/TFR  
Q750 = .875/TFR  
Q760 = .438/TFR  
Q770 = .292/TFR  
Q780 = .083/TFR  
Q790 = .042/TFR  
Q80(1) = 2.0/TFR  
Q81(1) = 1.0/TFR  
Q82(1) = 1.0/TFR  
Q830 = 6.63/TFR  
Q840 = 4.73/TFR  
Q850 = 4.43/TFR  
Q860 = .575/TFR  
Q870 = .60/TFR  
Q880 = 4.21/TFR  
Q890 = 10.44/TFR  
Q900 = 8.93/TFR  
Q910 = 7.58/TFR  
Q920 = .05/TFR  
Q930 = .708/TFR  
Q940 = 4.01/TFR  
Q95(1) = 9.88/TFR  
Q96(1) = 4.51/TFR  
Q97(1) = 1.91/TFR  
Q980 = 6.55/TFR  
Q990 = 3.68/TFR  
Q1000 = 1.47/TFR  
Q1010 = 8.51/TFR  
Q1020 = 1.43/TFR  
Q1030 = 2.72/TFR  
Q104(1) = 15.23/TFR  
Q105(1) = 1.05/TFR  
Q106(1) = 7.26/TFR  
ALP1 = 0.90/TFR  
ALP2 = 0.90/TFR  
ALP3 = 0.90/TFR  
ALP4 = 0.90/TFR  
ALP5 = 0.90/TFR

Figure D-1. Continued.

```

ALP6 = 0.90/TFR
ALP6B = 0.90/TFR
ALP7 = 0.90/TFR
ALP8 = 0.90/TFR
ALP9 = 0.90/TFR
ALP10 = 0.90/TFR
ALP11 = 0.90/TFR
DEL1 = 0.175/TFR
DEL2 = 0.375/TFR
DEL3 = 0.30/TFR
DEL4 = 0.10/TFR
DEL5 = 0.275/TFR
DEL6 = 0.25/TFR
DEL7 = 0.25/TFR
DEL8 = 0.15/TFR
DEL9 = 0.10/TFR
DEL10 = 0.10/TFR
DEL11 = 0.15/TFR
U1(1) = U(1)
U1A(1) = U(2)
U2(1) = U(3)
U3(1) = U(4)
U3A(1) = U(5)
U4(1) = U(6)
U4A(1) = U(7)
U5(1) = U(8)
U6(1) = U(9)
U6B(1) = U(10)
U7(1) = U(11)
U8(1) = U(12)
U9(1) = U(13)
U10(1) = U(14)
U11(1) = U(15)
U11A(1) = U(16)
DO 218 K = 1,91
U1(K) = U1(1)
U1A(K) = U1A(1)
U2(K) = U2(1)
U3(K) = U3(1)
U3A(K) = U3A(1)
U4(K) = U4(1)
U4A(K) = U4A(1)
U5(K) = U5(1)
U6(K) = U6(1)
U6B(K) = U6B(1)
U7(K) = U7(1)
U8(K) = U8(1)
U9(K) = U9(1)
U10(K) = U10(1)
U11(K) = U11(1)
U11A(K) = U11A(1)
Q1(K) = Q1(1)
Q2(K) = Q2(1)
Q3(K) = Q3(1)

```

Figure D-1. Continued.

```

Q4(K) = Q4(1)
Q5(K) = Q5(1)
Q6(K) = Q6(1)
Q10(K) = Q10(1)
Q11(K) = Q11(1)
Q12(K) = Q12(1)
Q17(K) = Q17(1)
Q18(K) = Q18(1)
Q19(K) = Q19(1)
Q20(K) = Q20(1)
Q21(K) = Q21(1)
Q37(K) = Q37(1)
Q38(K) = Q38(1)
Q39(K) = Q39(1)
Q49(K) = Q49(1)
Q50(K) = Q50(1)
Q58(K) = Q58(1)
Q59(K) = Q59(1)
Q60(K) = Q60(1)
Q67(K) = Q67(1)
Q68(K) = Q68(1)
Q80(K) = Q80(1)
Q81(K) = Q81(1)
Q82(K) = Q82(1)
Q95(K) = Q95(1)
Q96(K) = Q96(1)
Q97(K) = Q97(1)
Q104(K) = Q104(1)
Q105(K) = Q105(1)
Q106(K) = Q106(1)
218 CONTINUE
DO 220 K=1,91
  L=K+1
  MK=K-1
  KN=K-3
  M=K-4
  NL=K-6
  KM=K-7
  ML=K-9
  NN=K-12
  JJ=K-13
C
C *** INTERSECTION 452 BYRNE-AIRPORT HWAY
C
  D1(K) = S1*U1(K)
  W1(K) = X1(K) + Q1(K)
  IF (W1(K) .GT. D1(K)) GO TO 10
  IF (W1(K) .LT. D1(K)) D1(K) = W1(K)
10  X1(L) = X1(K) - D1(K) + Q1(K)
  D2(K) = S2*U1(K)
  W2(K) = X2(K) + Q2(K)
  IF (W2(K) .GT. D2(K)) GO TO 12
  IF (W2(K) .LT. D2(K)) D2(K) = W2(K)
12  X2(L) = X2(K) - D2(K) + Q2(K)

```

Figure D-1. Continued.



```

D3(K) = S3*U1A(K)
W3(K) = X3(K) + Q3(K)
IF (W3(K) .GT. D3(K)) GO TO 14
IF (W3(K) .LT. D3(K)) D3(K) = W3(K)
14 X3(L) = X3(K) - D3(K) + Q3(K)
D4(K) = S4*U1(K)
W4(K) = X4(K) + Q4(K)
IF (W4(K) .GT. D4(K)) GO TO 16
IF (W4(K) .LT. D4(K)) D4(K) = W4(K)
16 X4(L) = X4(K) - D4(K) + Q4(K)
D5(K) = S5*U1(K)
W5(K) = X5(K) + Q5(K)
IF (W5(K) .GT. D5(K)) GO TO 18
IF (W5(K) .LT. D5(K)) D5(K) = W5(K)
18 X5(L) = X5(K) + Q5(K) - D5(K)
D6(K) = S6*U1A(K)
W6(K) = X6(K) + Q6(K)
IF (W6(K) .GT. D6(K)) GO TO 20
IF (W6(K) .LT. D6(K)) D6(K) = W6(K)
20 X6(L) = X6(K) - D6(K) + Q6(K)
D7(K) = S7*(ALP1 - U1(K) - U1A(K) - DEL1)
Q7(K) = .83*(D15(M)+D17(M))
IF (K .LE. 4) Q7(K) = Q70A
W7(K) = X7(K) + Q7(K)
IF (W7(K) .GT. D7(K)) GO TO 22
IF (W7(K) .LT. D7(K)) D7(K) = W7(K)
22 X7(L) = X7(K) - D7(K) + Q7(K)
D8(K) = S8*(ALP1 - U1(K) - U1A(K) - DEL1)
Q8(K) = .07*Q7(K)/.83
IF (K .LE. 4) Q8(K) = Q80A
W8(K) = X8(K) + Q8(K)
IF (W8(K) .GT. D8(K)) GO TO 24
IF (W8(K) .LT. D8(K)) D8(K) = W8(K)
24 X8(L) = X8(K) + Q8(K) - D8(K)
D9(K) = S9*DEL1
Q9(K) = .10*Q7(K)/.83
IF (K .LE. 4) Q9(K) = Q90A
W9(K) = X9(K) + Q9(K)
IF (W9(K) .GT. D9(K)) GO TO 26
IF (W9(K) .LT. D9(K)) D9(K) = W9(K)
26 X9(L) = X9(K) - D9(K) + Q9(K)
D10(K) = S10*(ALP1 - U1(K) - U1A(K) - DEL1)
W10(K) = X10(K) + Q10(K)
IF (W10(K) .GT. D10(K)) GO TO 28
IF (W10(K) .LT. D10(K)) D10(K) = W10(K)
28 X10(L) = X10(K) - D10(K) + Q10(K)
D11(K) = S11*(ALP1 - U1(K) - U1A(K) - DEL1)
W11(K) = X11(K) + Q11(K)
IF (W11(K) .GT. D11(K)) GO TO 30
IF (W11(K) .LT. D11(K)) D11(K) = W11(K)
30 X11(L) = X11(K) + Q11(K) - D11(K)
D12(K) = S12*DEL1
W12(K) = X12(K) + Q12(K)
IF (W12(K) .GT. D12(K)) GO TO 32

```

Figure D-1. Continued.

```

      IF (W12(K) .LT. D12(K)) D12(K) = W12(K)
32  X12(L) = X12(K) + Q12(K) - D12(K)
C
C *** INTERSECTION 560 BYRNE-ARLINGTON
C
      Q13(K) = .69*(D10(M)+D2(M)+D6(M))
      IF (K .LE. 4) Q13(K) = Q130
      D13(K) = S13*U2(K)
      W13(K) = X13(K) + Q13(K)
      IF (W13(K) .GT. D13(K)) GO TO 34
      IF (W13(K) .LT. D13(K)) D13(K) = W13(K)
34  X13(L) = X13(K) + Q13(K) - D13(K)
      D14(K) = S14*DEL2
      Q14(K) = .31*Q13(K)/.69
      IF (K .LE. 4) Q14(K) = Q140
      W14(K) = X14(K) + Q14(K)
      IF (W14(K) .GT. D14(K)) GO TO 36
      IF (W14(K) .LT. D14(K)) D14(K) = W14(K)
36  X14(L) = X14(K) + Q14(K) - D14(K)
      D15(K) = S15*(U2(K) - DEL2)
      Q15(K) = .94*(D25(M)+D21(M)+D23(M))
      IF (K .LE. 4) Q15(K) = Q150
      W15(K) = X15(K) + Q15(K)
      IF (W15(K) .GT. D15(K)) GO TO 38
      IF (W15(K) .LT. D15(K)) D15(K) = W15(K)
38  X15(L) = X15(K) + Q15(K) - D15(K)
      D16(K) = S16*(U2(K) - DEL2)
      Q16(K) = .06*Q15(K)/.94
      IF (K .LE. 4) Q16(K) = Q160
      W16(K) = X16(K) + Q16(K)
      IF (W16(K) .GT. D16(K)) GO TO 40
      IF (W16(K) .LT. D16(K)) D16(K) = W16(K)
40  X16(L) = X16(K) + Q16(K) - D16(K)
      D17(K) = S17*(ALP2 - U2(K) + .2*DEL2)
      W17(K) = X17(K) + Q17(K)
      IF (W17(K) .GT. D17(K)) GO TO 42
      IF (W17(K) .LT. D17(K)) D17(K) = W17(K)
42  X17(L) = X17(K) - D17(K) + Q17(K)
      D18(K) = S18*(ALP2 - U2(K))
      W18(K) = X18(K) + Q18(K)
      IF (W18(K) .GT. D18(K)) GO TO 44
      IF (W18(K) .LT. D18(K)) D18(K) = W18(K)
44  X18(L) = X18(K) - D18(K) + Q18(K)
C
C *** INTERSECTION A BYRNE-GLENDALE
C
      D19(K) = S19*(ALP3 - U3(K) - U3A(K) - DEL3)
      W19(K) = X19(K) + Q19(K)
      IF (W19(K) .GT. D19(K)) GO TO 46
      IF (W19(K) .LT. D19(K)) D19(K) = W19(K)
46  X19(L) = X19(K) - D19(K) + Q19(K)
C
C *** INTERSECTION 413 BYRNE-HEATHERDOWNS
C

```

Figure D-1. Continued.

```

D20(K) = S20*(ALP3 - U3(K) - U3A(K) - DEL3)
W20(K) = X20(K) + Q20(K)
IF (W20(K) .GT. D20(K)) GO TO 48
IF (W20(K) .LT. D20(K)) D20(K) = W20(K)
48 X20(L) = X20(K) - D20(K) + Q20(K)
D21(K) = S21*DEL3
W21(K) = X21(K) + Q21(K)
IF (W21(K) .GT. D21(K)) GO TO 50
IF (W21(K) .LT. D21(K)) D21(K) = W21(K)
50 X21(L) = X21(K) + Q21(K) - D21(K)
D22(K) = S22*(ALP3 - U3(K) - U3A(K) - DEL3)
Q22(K) = 0.41*(D104(NN)+D96(NN)+D100(NN))
IF (K .LE. 12) Q22(K) = Q220
W22(K) = X22(K) + Q22(K)
IF (W22(K) .GT. D22(K)) GO TO 52
IF (W22(K) .LT. D22(K)) D22(K) = W22(K)
52 X22(L) = X22(K) - D22(K) + Q22(K)
D23(K) = S23*(ALP3 - U3(K) - U3A(K) - .5*DEL3)
Q23(K) = .33*Q22(K)/.41
IF (K .LE. 12) Q23(K) = Q230
W23(K) = X23(K) + Q23(K)
IF (W23(K) .GT. D23(K)) GO TO 54
IF (W23(K) .LT. D23(K)) D23(K) = W23(K)
54 X23(L) = X23(K) - D23(K) + Q23(K)
D24(K) = S24*DEL3
Q24(K) = .260*Q22(K)/.41
IF (K .LE. 12) Q24(K) = Q240
W24(K) = X24(K) + Q24(K)
IF (W24(K) .GT. D24(K)) GO TO 56
IF (W24(K) .LT. D24(K)) D24(K) = W24(K)
56 X24(L) = X24(K) + Q24(K) - D24(K)
D25(K) = S25*U3(K)
Q25(K) = .74*(D31(KM)+D41(KM)+D39(KM) + .5*D90(NN) + .5*D92(NN))
IF (K .LE. 12) Q25(K) = Q250
W25(K) = X25(K) + Q25(K)
IF (W25(K) .GT. D25(K)) GO TO 58
IF (W25(K) .LT. D25(K)) D25(K) = W25(K)
58 X25(L) = X25(K) - D25(K) + Q25(K)
D26(K) = S26*U3(K)
Q26(K) = .24*Q25(K)/.74
IF (K .LE. 12) Q26(K) = Q260
W26(K) = X26(K) + Q26(K)
IF (W26(K) .GT. D26(K)) GO TO 60
IF (W26(K) .LT. D26(K)) D26(K) = W26(K)
60 X26(L) = X26(K) - D26(K) + Q26(K)
D27(K) = S27*U3A(K)
Q27(K) = 0.02*Q25(K)/0.74
IF (K .LE. 12) Q27(K) = Q270
W27(K) = X27(K) + Q27(K)
IF (W27(K) .GT. D27(K)) GO TO 62
IF (W27(K) .LT. D27(K)) D27(K) = W27(K)
62 X27(L) = X27(K) + Q27(K) - D27(K)
D28(K) = S28*U3(K)
Q28(K) = .65*(D13(M)+D18(M))

```

Figure D-1. Continued.

```

IF (K .LE. 4) Q28(K) = Q280
W28(K) = X28(K) + Q28(K)
IF (W28(K) .GT. D28(K)) GO TO 64
IF (W28(K) .LT. D28(K)) D28(K) = W28(K)
64 X28(L) = X28(K) + Q28(K) - D28(K)
D29(K) = S29*U3(K)
Q29(K) = .26*Q28(K)/.65
IF (K .LE. 4) Q29(K) = Q290
W29(K) = X29(K) + Q29(K)
IF (W29(K) .GT. D29(K)) GO TO 66
IF (W29(K) .LT. D29(K)) D29(K) = W29(K)
66 X29(L) = X29(K) - D29(K) + Q29(K)
D30(K) = S30*U3A(K)
Q30(K) = .09*Q28(K)/.65
IF (K .LE. 4) Q30(K) = Q300
W30(K) = X30(K) + Q30(K)
IF (W30(K) .GT. D30(K)) GO TO 68
IF (W30(K) .LT. D30(K)) D30(K) = W30(K)
68 X30(L) = X30(K) - D30(K) + Q30(K)

C
C *** INTERSECTION 413 BYRNE-HEATHERDOWNS
C
D31(K) = S31*U4(K)
Q31(K) = 0.73*(D43(MK) + .91*D52(MK))
IF (K .LE. 1) Q31(K) = Q310
W31(K) = X31(K) + Q31(K)
IF (W31(K) .GT. D31(K)) GO TO 70
IF (W31(K) .LT. D31(K)) D31(K) = W31(K)
70 X31(L) = X31(K) - D31(K) + Q31(K)
D32(K) = S32*U4(K)
Q32(K) = .24*Q31(K)/.73
IF (K .LE. 1) Q32(K) = Q320
W32(K) = X32(K) + Q32(K)
IF (W32(K) .GT. D32(K)) GO TO 72
IF (W32(K) .LT. D32(K)) D32(K) = W32(K)
72 X32(L) = X32(K) - D32(K) + Q32(K)
D33(K) = S33*DEL4
Q33(K) = .03*Q31(K)/.73
IF (K .LE. 1) Q33(K) = Q330
W33(K) = X33(K) + Q33(K)
IF (W33(K) .GT. D33(K)) GO TO 74
IF (W33(K) .LT. D33(K)) D33(K) = W33(K)
74 X33(L) = X33(K) + Q33(K) - D33(K)
D34(K) = S34*(U4(K) - DEL4)
Q34(K) = .55*.8*(D28(KM) + D20(KM) + D24(KM))
IF (K .LE. 7) Q34(K) = Q340
W34(K) = X34(K) + Q34(K)
IF (W34(K) .GT. D34(K)) GO TO 76
IF (W34(K) .LT. D34(K)) D34(K) = W34(K)
76 IF (MK .LT. 1) W46(MK) = X46(1) + Q460
IF (MK .LT. 1) W47(MK) = X47(1) + Q470
IF (MK .LT. 1) W48(MK) = X48(1) + Q480
IF (W46(MK) .GE. XM46) D34(K) = 0.
IF (W47(MK) .GE. XM47) D34(K) = 0.

```

Figure D-1. Continued.

```

IF (W48(MK) .GE. XM48) D34(K)=0.
X34(L) = X34(K) - D34(K) + Q34(K)
D35(K) = S35*(U4(K) - DEL4)
Q35(K) = .45*Q34(K)/.55
IF (K .LE. 7) Q35(K) = Q350
W35(K) = X35(K) + Q35(K)
IF (W35(K) .GT. D35(K)) GO TO 78
IF (W35(K) .LT. D35(K)) D35(K) = W35(K)
78 X35(L) = X35(K) - D35(K) + Q35(K)
D37(K) = S37*(ALP4 - U4(K) - U4A(K))
W37(K) = X37(K) + Q37(K)
IF (W37(K) .GT. D37(K)) GO TO 82
IF (W37(K) .LT. D37(K)) D37(K) = W37(K)
82 X37(L) = X37(K) - D37(K) + Q37(K)
D38(K) = S38*(ALP4 - U4(K) - U4A(K) + DEL4)
W38(K) = X38(K) + Q38(K)
IF (W38(K) .GT. D38(K)) GO TO 84
IF (W38(K) .LT. D38(K)) D38(K) = W38(K)
84 IF (MK .LT. 1) W46(MK)=X46(1)+Q460
IF (MK .LT. 1) W47(MK)=X47(1)+Q470
IF (MK .LT. 1) W48(MK)=X48(1)+Q480
IF (W46(MK) .GE. XM46) D38(K)=0.
IF (W47(MK) .GE. XM47) D38(K)=0.
IF (W48(MK) .GE. XM48) D38(K)=0.
X38(L) = X38(K) - D38(K) + Q38(K)
D39(K) = S39*U4A(K)
W39(K) = X39(K) + Q39(K)
IF (W39(K) .GT. D39(K)) GO TO 86
IF (W39(K) .LT. D39(K)) D39(K) = W39(K)
86 X39(L) = X39(K) + Q39(K) - D39(K)
D40(K) = S40*(ALP4 - U4(K) - U4A(K))
Q40(K) = .78*.5*(D90(JJ)+D92(JJ))
IF (K .LE. 13) Q40(K) = Q400
W40(K) = X40(K) + Q40(K)
IF (W40(K) .GT. D40(K)) GO TO 88
IF (W40(K) .LT. D40(K)) D40(K) = W40(K)
88 X40(L) = X40(K) + Q40(K) - D40(K)
D41(K) = S41*(ALP4 - U4(K) - U4A(K))
Q41(K) = .14*Q40(K)/.78
IF (K .LE. 13) Q41(K) = Q410
W41(K) = X41(K) + Q41(K)
IF (W41(K) .GT. D41(K)) GO TO 90
IF (W41(K) .LT. D41(K)) D41(K) = W41(K)
90 X41(L) = X41(K) + Q41(K) - D41(K)
D42(K) = S42*U4A(K)
Q42(K) = .08*Q40(K)/.78
IF (K .LE. 13) Q42(K) = Q420
W42(K) = X42(K) + Q42(K)
IF (W42(K) .GT. D42(K)) GO TO 92
IF (W42(K) .LT. D42(K)) D42(K) = W42(K)
92 IF (MK .LT. 1) W46(MK)=X46(1)+Q460
IF (MK .LT. 1) W47(MK)=X47(1)+Q470
IF (MK .LT. 1) W48(MK)=X48(1)+Q480
IF (W46(MK) .GE. XM46) D42(K)=0.

```

Figure D-1. Continued.

```

IF (W47(MK) .GE. XM47) D42(K)=0.
IF (W48(MK) .GE. XM48) D42(K)=0.
X42(L) = X42(K) + Q42(K) - D42(K)

C
C *** INTERSECTION 588 BYRNE-GLANZMAN
C
D43(K) = S43*U5(K)
Q43(K) = .93*D53B(NL)
IF (K .LE. 6) Q43(K) = Q430
W43(K) = X43(K) + Q43(K)
IF (W43(K) .GT. D43(K)) GO TO 94
IF (W43(K) .LT. D43(K)) D43(K) = W43(K)
94 IF (MK .LT. 1) W31(MK)=X31(1)+Q310
IF (MK .LT. 1) W32(MK)=X32(1)+Q320
IF (MK .LT. 1) W33(MK)=X33(1)+Q330
IF (W31(MK) .GE. XM31) D43(K)=0.
IF (W32(MK) .GE. XM32) D43(K)=0.
IF (W33(MK) .GE. XM33) D43(K)=0.
X43(L) = X43(K) + Q43(K) - D43(K)
D44(K) = S44*U5(K)
Q44(K) = .03*Q43(K)/.93
IF (K .LE. 6) Q44(K) = Q440
W44(K) = X44(K) + Q44(K)
IF (W44(K) .GT. D44(K)) GO TO 96
IF (W44(K) .LT. D44(K)) D44(K) = W44(K)
96 X44(L) = X44(K) + Q44(K) - D44(K)
D45(K) = S45*DEL5
Q45(K) = .04*Q43(K)/.93
IF (K .LE. 6) Q45(K)=Q450
W45(K) = X45(K) + Q45(K)
IF (W45(K) .GT. D45(K)) GO TO 98
IF (W45(K) .LT. D45(K)) D45(K) = W45(K)
98 X45(L) = X45(K) - D45(K) + Q45(K)
D46(K) = S46*U5(K)
Q46(K) = .58*(D34(MK)+D38(MK)+D42(MK))
IF (K .LE. 1) Q46(K)=Q460
W46(K) = X46(K) + Q46(K)
IF (W46(K) .GT. D46(K)) GO TO 100
IF (W46(K) .LT. D46(K)) D46(K) = W46(K)
100 X46(L) = X46(K) - D46(K) + Q46(K)
D47(K) = S47*U5(K)
Q47(K) = .08*Q46(K)/.58
IF (K .LE. 1) Q47(K) = Q470
W47(K) = X47(K) + Q47(K)
IF (W47(K) .GT. D47(K)) GO TO 102
IF (W47(K) .LT. D47(K)) D47(K) = W47(K)
102 X47(L) = X47(K) - D47(K) + Q47(K)
D48(K) = S48*DEL5
Q48(K) = .34*Q46(K)/.58
IF (K .LE. 1) Q48(K) = Q480
W48(K) = X48(K) + Q48(K)
IF (W48(K) .GT. D48(K)) GO TO 104
IF (W48(K) .LT. D48(K)) D48(K) = W48(K)
104 X48(L) = X48(K) - D48(K) + Q48(K)

```

Figure D-1. Continued.

```

D49(K) = S49*(ALP5 - U5(K) - DEL5)
W49(K) = X49(K) + Q49(K)
IF (W49(K) .GT. D49(K)) GO TO 106
IF (W49(K) .LT. D49(K)) D49(K) = W49(K)
106 X49(L) = X49(K) + Q49(K) - D49(K)
D50(K) = S50*(ALP5 - U5(K) - DEL5)
W50(K) = X50(K) + Q50(K)
IF (W50(K) .GT. D50(K)) GO TO 108
IF (W50(K) .LT. D50(K)) D50(K) = W50(K)
108 X50(L) = X50(K) - D50(K) + Q50(K)
D51(K) = S51*(ALP5 - U5(K) - DEL5)
Q51(K) = .07*(D84(ML)+D86(ML))
IF (K .LE. 9) Q51(K) = Q510
W51(K) = X51(K) + Q51(K)
IF (W51(K) .GT. D51(K)) GO TO 110
IF (W51(K) .LT. D51(K)) D51(K) = W51(K)
110 X51(L) = X51(K) - D51(K) + Q51(K)
D52(K) = S52*(ALP5 - .5*U5(K) - DEL5)
Q52(K) = .93*(D84(ML)+D86(ML))
IF (K .LE. 9) Q52(K) = Q520
W52(K) = X52(K) + Q52(K)
IF (W52(K) .GT. D52(K)) GO TO 112
IF (W52(K) .LT. D52(K)) D52(K) = W52(K)
112 IF (MK .LT. 1) W31(MK)=X31(1)+Q310
IF (MK .LT. 1) W32(MK)=X32(1)+Q320
IF (MK .LT. 1) W33(MK)=X33(1)+Q330
IF (W31(MK) .GE. XM31) D52(K)=0.
IF (W32(MK) .GE. XM32) D52(K)=0.
IF (W33(MK) .GE. XM33) D52(K)=0.
X52(L) = X52(K) + Q52(K) - D52(K)

C
C *** INTERSECTION 360 BYRNE-COPLAND-FOLKSTONE
C
D53(K) = S53*(U6(K) - DEL6)
Q53(K) = .86*(.286*D70(KN)+.974*D68(KN))
IF (K .LE. 3) Q53(K) = Q530
W53(K) = X53(K) + Q53(K)
IF (W53(K) .GT. D53(K)) GO TO 114
IF (W53(K) .LT. D53(K)) D53(K) = W53(K)
114 IF (MK .LT. 1) W53B(MK) = X53B(1)+Q530+.7*Q620
IF (W53B(MK) .GE. XM53B) D53(K)=0.
X53(L) = X53(K) - D53(K) + Q53(K)
D53B(K) = S53B*U6B(K)
Q53B(K) = D53(K) + .7*D62(K)
IF (K .LE. 3) Q53B(K) = Q530+.7*Q620
IF (W53B(K) .GT. XM53B) Q53B(K) = 0.
W53B(K) = X53B(K) + Q53B(K)
IF (W53B(K) .GT. D53B(K)) GO TO 115
IF (W53B(K) .LT. D53B(K)) D53B(K) = W53B(K)
115 X53B(L) = X53B(K) - D53B(K) + Q53B(K)
D54(K) = S54*(U6(K) - DEL6)
Q54(K) = .14*Q53(K)/.86
IF (K .LE. 3) Q54(K) = Q530
W54(K) = X54(K) + Q54(K)

```

Figure D-1. Continued.

```

      IF (W54(K) .GT. D54(K)) GO TO 116
      IF (W54(K) .LT. D54(K)) D54(K) = W54(K)
116  X54(L) = X54(K) - D54(K) + Q54(K)
      D55(K) = S55*U6B(K)
      Q55(K) = .76*(D46(NL)+D50(NL))
      IF (K .LE. 6) Q55(K) = Q550
      W55(K) = X55(K) + Q55(K)
      IF (W55(K) .GT. D55(K)) GO TO 118
      IF (W55(K) .LT. D55(K)) D55(K) = W55(K)
118  IF (MK .LT. 1) W64(MK) = X64(1)+Q640
      IF (W64(MK) .GE. XM64) D55(K) = 0.
      IF (W57(MK) .GE. XM57) D55(K) = 0.
      X55(L) = X55(K) + Q55(K) - D55(K)
      D56(K) = S56*U6B(K)
      Q56(K) = .01*Q55(K)/.76
      IF (K .LE. 6) Q56(K) = Q560
      W56(K) = X56(K) + Q56(K)
      IF (W56(K) .GT. D56(K)) GO TO 120
      IF (W56(K) .LT. D56(K)) D56(K) = W56(K)
120  X56(L) = X56(K) + Q56(K) - D56(K)
      D57(K) = S57*DEL6
      Q57(K) = .23*D55(K)
      IF (W57(MK) .GT. XM57) Q57(K) = 0.
      W57(K) = X57(K) + Q57(K)
      IF (W57(K) .GT. D57(K)) GO TO 122
      IF (W57(K) .LT. D57(K)) D57(K) = W57(K)
122  X57(L) = X57(K) + Q57(K) - D57(K)
      D58(K) = S58*(ALP6B - U6B(K))
      W58(K) = X58(K) + Q58(K)
      IF (W58(K) .GT. D58(K)) GO TO 124
      IF (W58(K) .LT. D58(K)) D58(K) = W58(K)
124  X58(L) = X58(K) + Q58(K) - D58(K)
      D59(K) = S59*(ALP6B - U6B(K))
      W59(K) = X59(K) + Q59(K)
      IF (W59(K) .GT. D59(K)) GO TO 126
      IF (W59(K) .LT. D59(K)) D59(K) = W59(K)
126  IF (MK .LT. 1) W64(MK) = X64(1)+Q640
      IF (W64(MK) .GE. XM64) D59(K) = 0.
      X59(L) = X59(K) - D59(K) + Q59(K)
      D60(K) = S60*(ALP6B - U6B(K))
      W60(K) = X60(K) + Q60(K)
      IF (W60(K) .GT. D60(K)) GO TO 128
      IF (W60(K) .LT. D60(K)) D60(K) = W60(K)
128  IF (MK .LT. 1) W64(MK) = X64(1)+Q640
      IF (W64(MK) .GE. XM64) D60(K) = 0.
      X60(L) = X60(K) - D60(K) + Q60(K)
      D61(K) = S61*(ALP6 - U6(K))
      Q61(K) = .03*(D80(KN) + D72(KN) + D76(KN))
      IF (K .LE. 3) Q61(K) = Q610
      W61(K) = X61(K) + Q61(K)
      IF (W61(K) .GT. D61(K)) GO TO 130
      IF (W61(K) .LT. D61(K)) D61(K) = W61(K)
130  X61(L) = X61(K) - D61(K) + Q61(K)
      D62(K) = S62*(ALP6 - U6(K) + DEL6)

```

Figure D-1. Continued.



```

Q62(K) = .83*(D80(KN)+D72(KN)+D76(KN))
IF (K .LE. 3) Q62(K) = Q620
W62(K) = X62(K) + Q62(K)
IF (W62(K) .GT. D62(K)) GO TO 132
IF (W62(K) .LT. D62(K)) D62(K) = W62(K)
132 IF (MK .LT. 1) W53B(MK) = X53B(1)+Q530+.7*Q620
IF (W53B(MK) .GE. XM53B) D62(K) = 0.
X62(L) = X62(K) - D62(K) + Q62(K)
D63(K) = S63*(ALP6 - U6(K))
Q63(K) = .14*Q62(K)/.83
IF (K .LE. 3) Q63(K) = Q630
W63(K) = X63(K) + Q63(K)
IF (W63(K) .GT. D63(K)) GO TO 134
IF (W63(K) .LT. D63(K)) D63(K) = W63(K)
134 X63(L) = X63(K) + Q63(K) - D63(K)
D64(K) = S64*U6(K)
Q64(K) = .77*D55(K)+D59(K)+.7*D60(K)
IF (W64(K) .GT. XM64) Q64(K) = 0.
W64(K) = X64(K) + Q64(K)
IF (W64(K) .GT. D64(K)) GO TO 136
IF (W64(K) .LT. D64(K)) D64(K) = W64(K)
136 X64(L) = X64(K) - D64(K) + Q64(K)
C
C *** INTERSECTION 361 BYRNE-DETROIT
C
D65(K) = S65*(ALP7 - U7(K))
Q65(K) = .93*(D64(KN)+D63(KN))
IF (K .LE. 3) Q65(K) = Q650
W65(K) = X65(K) + Q65(K)
IF (W65(K) .GT. D65(K)) GO TO 138
IF (W65(K) .LT. D65(K)) D65(K) = W65(K)
138 X65(L) = X65(K) - D65(K) + Q65(K)
D66(K) = S66*(ALP7 - U7(K))
Q66(K) = .07*Q65(K)/.93
IF (K .LE. 3) Q66(K) = Q660
W66(K) = X66(K) + Q66(K)
IF (W66(K) .GT. D66(K)) GO TO 140
IF (W66(K) .LT. D66(K)) D66(K) = W66(K)
140 X66(L) = X66(K) + Q66(K) - D66(K)
D67(K) = S67*U7(K)
W67(K) = X67(K) + Q67(K)
IF (W67(K) .GT. D67(K)) GO TO 142
IF (W67(K) .LT. D67(K)) D67(K) = W67(K)
142 X67(L) = X67(K) - D67(K) + Q67(K)
D68(K) = S68*DEL7
W68(K) = X68(K) + Q68(K)
IF (W68(K) .GT. D68(K)) GO TO 144
IF (W68(K) .LT. D68(K)) D68(K) = W68(K)
144 X68(L) = X68(K) - D68(K) + Q68(K)
D69(K) = S69*(U7(K) - DEL7)
Q69(K) = .79*(D71(M)+D78(M)+D82(M))
IF (K .LE. 4) Q69(K) = Q690
W69(K) = X69(K) + Q69(K)
IF (W69(K) .GT. D69(K)) GO TO 146

```

Figure D-1. Continued.

```

      IF (W69(K) .LT. D69(K)) D69(K) = W69(K)
146  X69(L) = X69(K) + Q69(K) - D69(K)
      D70(K) = S70*(U7(K) - DEL7)
      Q70(K) = .21*Q69(K)/.79
      IF (K .LE. 4) Q70(K) = Q700
      W70(K) = X70(K) + Q70(K)
      IF (W70(K) .GT. D70(K)) GO TO 148
      IF (W70(K) .LT. D70(K)) D70(K) = W70(K)
148  X70(L) = X70(K) + Q70(K) - D70(K)

```

C

C \*\*\* INTERSECTION B DETROIT-COPLAND

C

```

      D71(K) = S71*U8(K)
      Q71(K) = .70*(D83(KM)+D87(KM))
      IF (K .LE. 7) Q71(K) = Q710
      W71(K) = X71(K) + Q71(K)
      IF (W71(K) .GT. D71(K)) GO TO 150
      IF (W71(K) .LT. D71(K)) D71(K) = W71(K)
150  X71(L) = X71(K) + Q71(K) - D71(K)
      D72(K) = S72*U8(K)
      Q72(K) = .20*Q71(K)/.70
      IF (K .LE. 7) Q72(K) = Q720
      W72(K) = X72(K) + Q72(K)
      IF (W72(K) .GT. D72(K)) GO TO 152
      IF (W72(K) .LT. D72(K)) D72(K) = W72(K)
152  X72(L) = X72(K) + Q72(K) - D72(K)
      D73(K) = S73*DEL8
      Q73(K) = .10*Q71(K)/.70
      IF (K .LE. 7) Q73(K) = Q730
      W73(K) = X73(K) + Q73(K)
      IF (W73(K) .GT. D73(K)) GO TO 154
      IF (W73(K) .LT. D73(K)) D73(K) = W73(K)
154  X73(L) = X73(K) + Q73(K) - D73(K)
      D74(K) = S74*U8(K)
      Q74(K) = .70*(D67(M)+D66(M))
      IF (K .LE. 4) Q74(K) = Q740
      W74(K) = X74(K) + Q74(K)
      IF (W74(K) .GT. D74(K)) GO TO 156
      IF (W74(K) .LT. D74(K)) D74(K) = W74(K)
156  X74(L) = X74(K) + Q74(K) - D74(K)
      D75(K) = S75*U8(K)
      Q75(K) = .20*Q74(K)/.70
      IF (K .LE. 4) Q75(K) = Q750
      W75(K) = X75(K) + Q75(K)
      IF (W75(K) .GT. D75(K)) GO TO 158
      IF (W75(K) .LT. D75(K)) D75(K) = W75(K)
158  X75(L) = X75(K) - D75(K) + Q75(K)
      D76(K) = S76*DEL8
      Q76(K) = .10*Q74(K)/.70
      IF (K .LE. 4) Q76(K) = Q760
      W76(K) = X76(K) + Q76(K)
      IF (W76(K) .GT. D76(K)) GO TO 160
      IF (W76(K) .LT. D76(K)) D76(K) = W76(K)
160  X76(L) = X76(K) - D76(K) + Q76(K)

```

Figure D-1. Continued.

```

D77(K) = S77*(ALP8 - U8(K) - DEL8 - DEL8)
Q77(K) = .70*(.929*D54(KN)+D57(KN))
IF (K .LE. 3) Q77(K) = Q770
W77(K) = X77(K) + Q77(K)
IF (W77(K) .GT. D77(K)) GO TO 162
IF (W77(K) .LT. D77(K)) D77(K) = W77(K)
162 X77(L) = X77(K) - D77(K) + Q77(K)
D78(K) = S78*(ALP8 - U8(K) - DEL8 - DEL8)
Q78(K) = .20*Q77(K)/.70
IF (K .LE. 3) Q78(K) = Q780
W78(K) = X78(K) + Q78(K)
IF (W78(K) .GT. D78(K)) GO TO 164
IF (W78(K) .LT. D78(K)) D78(K) = W78(K)
164 X78(L) = X78(K) - D78(K) + Q78(K)
D79(K) = S79*DEL8
Q79(K) = .10*Q77(K)/.70
IF (K .LE. 3) Q79(K) = Q790
W79(K) = X79(K) + Q79(K)
IF (W79(K) .GT. D79(K)) GO TO 166
IF (W79(K) .LT. D79(K)) D79(K) = W79(K)
166 X79(L) = X79(K) + Q79(K) - D79(K)
D80(K) = S80*(ALP8 - U8(K) - DEL8 - DEL8)
W80(K) = X80(K) + Q80(K)
IF (W80(K) .GT. D80(K)) GO TO 168
IF (W80(K) .LT. D80(K)) D80(K) = W80(K)
168 X80(L) = X80(K) - D80(K) + Q80(K)
D81(K) = S81*(ALP8 - U8(K) - DEL8 - DEL8)
W81(K) = X81(K) + Q81(K)
IF (W81(K) .GT. D81(K)) GO TO 170
IF (W81(K) .LT. D81(K)) D81(K) = W81(K)
170 X81(L) = X81(K) - D81(K) + Q81(K)
D82(K) = S82*DEL8
W82(K) = X82(K) + Q82(K)
IF (W82(K) .GT. D82(K)) GO TO 172
IF (W82(K) .LT. D82(K)) D82(K) = W82(K)
172 X82(L) = X82(K) + Q82(K) - D82(K)
C
C *** INTERSECTION C DETROIT-GLANZMAN
C
D83(K) = S83*(U9(K) - DEL9)
Q83(K) = .40*(D89(KN)+D93(KN))
IF (K .LE. 7) Q83(K) = Q830
W83(K) = X83(K) + Q83(K)
IF (W83(K) .GT. D83(K)) GO TO 174
IF (W83(K) .LT. D83(K)) D83(K) = W83(K)
174 X83(L) = X83(K) - D83(K) + Q83(K)
D84(K) = S84*(ALP9 - DEL9)
Q84(K) = .60*Q83(K)/.40
IF (K .LE. 7) Q84(K) = Q840
W84(K) = X84(K) + Q84(K)
IF (W84(K) .GT. D84(K)) GO TO 176
IF (W84(K) .LT. D84(K)) D84(K) = W84(K)
176 X84(L) = X84(K) - D84(K) + Q84(K)
D85(K) = S85*U9(K)

```

Figure D-1. Continued.

```

Q85(K) = .82*(D74(KM)+D79(KM)+D81(KM))
IF (K .LE. 7) Q85(K) = Q850
W85(K) = X85(K) + Q85(K)
IF (W85(K) .GT. D85(K)) GO TO 178
IF (W85(K) .LT. D85(K)) D85(K) = W85(K)
178 X85(L) = X85(K) + Q85(K) - D85(K)
D86(K) = S86*DEL9
Q86(K) = .18*Q85(K)/.82
IF (K .LE. 7) Q86(K) = Q860
W86(K) = X86(K) + Q86(K)
IF (W86(K) .GT. D86(K)) GO TO 180
IF (W86(K) .LT. D86(K)) D86(K) = W86(K)
180 X86(L) = X86(K) + Q86(K) - D86(K)
D87(K) = S_7*(ALP9 - U9(K))
Q87(K) = .08*(.667*D44(ML)+.986*D48(ML))
IF (K .LE. 9) Q87(K) = Q870
W87(K) = X87(K) + Q87(K)
IF (W87(K) .GT. D87(K)) GO TO 182
IF (W87(K) .LT. D87(K)) D87(K) = W87(K)
182 X87(L) = X87(K) + Q87(K) - D87(K)
D88(K) = S88*(ALP9 - U9(K))
Q88(K) = .92*(.667*D44(ML)+.986*D48(ML))
IF (K .LE. 9) Q88(K) = Q880
W88(K) = X88(K) + Q88(K)
IF (W88(K) .GT. D88(K)) GO TO 184
IF (W88(K) .LT. D88(K)) D88(K) = W88(K)
184 X88(L) = X88(K) + Q88(K) - D88(K)
C
C *** INTERSECTION 378 DETROIT-SCHNEIDER
C
D89(K) = S89*(U10(K) - DEL10)
Q89(K) = .73*(D95(KN)+D102(KN)+D106(KN))
IF (K .LE. 3) Q89(K) = Q890
W89(K) = X89(K) + Q89(K)
IF (W89(K) .GT. D89(K)) GO TO 186
IF (W89(K) .LT. D89(K)) D89(K) = W89(K)
186 X89(L) = X89(K) + Q89(K) - D89(K)
D90(K) = S90*(U10(K) - DEL10)
Q90(K) = .27*Q89(K)/.73
IF (K .LE. 3) Q90(K) = Q900
W90(K) = X90(K) + Q90(K)
IF (W90(K) .GT. D90(K)) GO TO 187
IF (W90(K) .LT. D90(K)) D90(K) = W90(K)
187 X90(L) = X90(K) - D90(K) + Q90(K)
D91(K) = S91*U10(K)
Q91(K) = .95*(D85(KM)+D88(KM))
IF (K .LE. 7) Q91(K) = Q910
W91(K) = X91(K) + Q91(K)
IF (W91(K) .GT. D91(K)) GO TO 188
IF (W91(K) .LT. D91(K)) D91(K) = W91(K)
188 X91(L) = X91(K) - D91(K) + Q91(K)
D92(K) = S92*DEL10
Q92(K) = .05*Q91(K)/.95
IF (K .LE. 7) Q92(K) = Q920

```

Figure D-1. Continued.

```

W92(K) = X92(K) + Q92(K)
IF (W92(K) .GT. D92(K)) GO TO 190
IF (W92(K) .LT. D92(K)) D92(K) = W92(K)
190 X92(L) = X92(K) + Q92(K) - D92(K)
D93(K) = S93*(ALP10 - U10(K))
Q93(K) = .08*(.20*(D28(NN)+D20(NN)+D24(NN))+D37(JJ)+D32(JJ))
IF (K .LE. 13) Q93(K) = Q930
W93(K) = X93(K) + Q93(K)
IF (W93(K) .GT. D93(K)) GO TO 192
IF (W93(K) .LT. D93(K)) D93(K) = W93(K)
192 X93(L) = X93(K) - D93(K) + Q93(K)
D94(K) = S94*(ALP10 - U10(K))
Q94(K) = .92*Q93(K)/.08
IF (K .LE. 13) Q94(K) = Q940
W94(K) = X94(K) + Q94(K)
IF (W94(K) .GT. D94(K)) GO TO 193
IF (W94(K) .LT. D94(K)) D94(K) = W94(K)
193 X94(L) = X94(K) - D94(K) + Q94(K)
C
C *** INTERSECTION 203 DETROIT-GLENDALE
C
D95(K) = S95*U11(K)
W95(K) = X95(K) + Q95(K)
IF (W95(K) .GT. D95(K)) GO TO 194
IF (W95(K) .LT. D95(K)) D95(K) = W95(K)
194 X95(L) = X95(K) + Q95(K) - D95(K)
D96(K) = S96*U11(K)
W96(K) = X96(K) + Q96(K)
IF (W96(K) .GT. D96(K)) GO TO 196
IF (W96(K) .LT. D96(K)) D96(K) = W96(K)
196 X96(L) = X96(K) + Q96(K) - D96(K)
D97(K) = S97*DEL11
W97(K) = X97(K) + Q97(K)
IF (W97(K) .GT. D97(K)) GO TO 197
IF (W97(K) .LT. D97(K)) D97(K) = W97(K)
197 X97(L) = X97(K) + Q97(K) - D97(K)
D98(K) = S98*U11(K)
Q98(K) = .52*(D91(KN)+D94(KN))
IF (K .LE. 3) Q98(K) = Q980
W98(K) = X98(K) + Q98(K)
IF (W98(K) .GT. D98(K)) GO TO 198
IF (W98(K) .LT. D98(K)) D98(K) = W98(K)
198 X98(L) = X98(K) + Q98(K) - D98(K)
D99(K) = S99*(U11(K)+U11A(K))
Q99(K) = .38*Q98(K)/.52
IF (K .LE. 3) Q99(K) = Q990
W99(K) = X99(K) + Q99(K)
IF (W99(K) .GT. D99(K)) GO TO 200
IF (W99(K) .LT. D99(K)) D99(K) = W99(K)
200 X99(L) = X99(K) - D99(K) + Q99(K)
D100(K) = S100*DEL11
Q100(K) = .10*Q98(K)/.52
IF (K .LE. 3) Q100(K) = Q1000
W100(K) = X100(K) + Q100(K)

```

Figure D-1. Continued.

```

      IF (W100(K) .GT. D100(K)) GO TO 202
      IF (W100(K) .LT. D100(K)) D100(K) = W100(K)
202  X100(L) = X100(K) + Q100(K) - D100(K)
      D101(K) = S101*(ALP11 - U11(K) - U11A(K) - DEL11)
      Q101(K) = .78*(D19(NN)+D26(NN)+D30(NN))
      IF (K .LE. 12) Q101(K) = Q1010
      W101(K) = X101(K) + Q101(K)
      IF (W101(K) .GT. D101(K)) GO TO 204
      IF (W101(K) .LT. D101(K)) D101(K) = W101(K)
204  X101(L) = X101(K) - D101(K) + Q101(K)
      D102(K) = S102*(ALP11 - U11(K) - U11A(K) - DEL11)
      Q102(K) = .04*Q101(K)/.78
      IF (K .LE. 12) Q102(K) = Q1020
      W102(K) = X102(K) + Q102(K)
      IF (W102(K) .GT. D102(K)) GO TO 206
      IF (W102(K) .LT. D102(K)) D102(K) = W102(K)
206  X102(L) = X102(K) - D102(K) + Q102(K)
      D103(K) = S103*U11A(K)
      Q103(K) = .18*Q101(K)/.78
      IF (K .LE. 12) Q103(K) = Q1030
      W103(K) = X103(K) + Q103(K)
      IF (W103(K) .GT. D103(K)) GO TO 208
      IF (W103(K) .LT. D103(K)) D103(K) = W103(K)
208  X103(L) = X103(K) + Q103(K) - D103(K)
      D104(K) = S104*(ALP11 - U11(K) - U11A(K) - DEL11)
      W104(K) = X104(K) + Q104(K)
      IF (W104(K) .GT. D104(K)) GO TO 210
      IF (W104(K) .LT. D104(K)) D104(K) = W104(K)
210  X104(L) = X104(K) + Q104(K) - D104(K)
      D105(K) = S105*(ALP11 - U11(K) - U11A(K) - DEL11)
      W105(K) = X105(K) + Q105(K)
      IF (W105(K) .GT. D105(K)) GO TO 212
      IF (W105(K) .LT. D105(K)) D105(K) = W105(K)
212  X105(L) = X105(K) + Q105(K) - D105(K)
      D106(K) = S106*U11A(K)
      W106(K) = X106(K) + Q106(K)
      IF (W106(K) .GT. D106(K)) GO TO 214
      IF (W106(K) .LT. D106(K)) D106(K) = W106(K)
214  X106(L) = X106(K) + Q106(K) - D106(K)
220  CONTINUE
      P=0.
      DO 245 J=91,91
      P1=W1(J)**2+W2(J)**2+W3(J)**2+W4(J)**2+W5(J)**2+W6(J)**2+W7(J)**2-
1+W8(J)**2+W9(J)**2+W10(J)**2+W11(J)**2+W12(J)**2+W13(J)**2
2+W14(J)**2+W15(J)**2+W16(J)**2+W17(J)**2+W18(J)**2+W19(J)**2
3+W20(J)**2+W21(J)**2+W22(J)**2+W23(J)**2+W24(J)**2+W25(J)**2
4+W26(J)**2+W27(J)**2+W28(J)**2+W29(J)**2+W30(J)**2+W31(J)**2
5+W32(J)**2+W33(J)**2+W34(J)**2+W35(J)**2+W36(J)**2+W37(J)**2
6+W38(J)**2+W39(J)**2+W40(J)**2+W41(J)**2+W42(J)**2+W43(J)**2
7+W44(J)**2+W45(J)**2+W46(J)**2+W47(J)**2+W48(J)**2+W49(J)**2
8+W50(J)**2+W51(J)**2+W52(J)**2+W53(J)**2
      P=P+P1
245  CONTINUE
      DO 250 J=91,91

```

Figure D-1. Continued.

```

P2=W53B(J)**2+W54(J)**2+W55(J)**2+W56(J)**2+W57(J)**2+W58(J)**2 -
1+W59(J)**2+W60(J)**2+W61(J)**2+W62(J)**2+W63(J)**2+W64(J)**2 -
3+W65(J)**2+W66(J)**2+W67(J)**2+W68(J)**2+W69(J)**2+W70(J)**2 -
4+W71(J)**2+W72(J)**2+W73(J)**2+W74(J)**2+W75(J)**2+W76(J)**2 -
5+W77(J)**2+W78(J)**2+W79(J)**2+W80(J)**2+W81(J)**2+W82(J)**2 -
6+W83(J)**2+W84(J)**2+W85(J)**2+W86(J)**2+W87(J)**2+W88(J)**2 -
7+W89(J)**2+W90(J)**2+W91(J)**2+W92(J)**2+W93(J)**2+W94(J)**2 -
8+W95(J)**2+W96(J)**2+W97(J)**2+W98(J)**2+W99(J)**2+W100(J)**2 -
9+W101(J)**2+W102(J)**2+W103(J)**2+W104(J)**2+W105(J)**2 -
A+W106(J)**2
P=P+P2
250 CONTINUE
DO 260 J=91,91
P3=R1*((U1(J)-.0234)**2)+R1A*((U1A(J)-.0167)**2) -
1+R2*((U2(J)-.070)**2)+R3*((U3(J)-.0400)**2) -
2+R3A*((U3A(J)-.010)**2)+R4*((U4(J)-.040)**2) -
3+R4A*((U4A(J)-.036)**2)+R5*((U5(J)-.030)**2) -
4+R6*((U6(J)-.047)**2)+R6B*((U6B(J)-.060)**2) -
5+R7*((U7(J)-.052)**2)+R8*((U8(J)-.052)**2) -
6+R9*((U9(J)-.049)**2)+R10*((U10(J)-.051)**2) -
7+R11*((U11(J)-.030)**2)+R11A*((U11A(J)-.015)**2)
P=P+P3
260 CONTINUE
P = P/105.
IF (P .LT. 1.000) P=P**.5
TMINA = P
RETURN
END

```

Figure D-1. Concluded.

#### BIBLIOGRAPHY.

1. Akashi, H., Yoshikawa, T., and Imai, H., Urban Traffic Control Based on Optimal Control Theory, IFAC Transactions, Transportation (June 1972).
2. Bleyl, R. L., A Practical Computer Program for Designing Traffic Signal System Timing Plans, Highway Research Record 211: 19-33 (1967).
3. Brent, R. P., Algorithms for Minimization Without Derivatives, Prentice-Hall, 124-127 (1973).
4. Drew, D. R., Traffic Flow Theory and Control, McGraw-Hill (1968).
5. Edie, L. C., Car-Following and Steady State Theory for Noncongested Traffic, Operations Research, Vol. 9: 66-76 (1961).
6. Gabbay, H., Gartner, N., and Little, J. D. C., Optimization of Traffic Signal Settings by Mixed Integer Linear Programming, Transportation Science 9: 321-363 (Nov. 1975).
7. Gartner, N., Algorithms for Dynamic Road Traffic Control, IFAC Transactions, Transportation: (1972).
8. Gartner, N., Microscopic Analysis of Traffic Flow Patterns for Minimizing Delay on Signal Controlled Links, Highway Research Record: 12-24 (1972).
9. Gazis, D. C., Traffic Control, Time Space Diagram and Networks, Traffic Control Theory and Instrumentation: 47-63 (1965).



10. Gazis, D. C., Optimum Control of a System of Oversaturated Intersections, IBM Journal: 815-831 (1964).
11. Gazis, D. C., and Edie, L. C., Traffic Flow Theory, Proceedings of the IEEE 56: 458-471 (April 1968).
12. Gazis, D. C., Herman, R., and Potts, R. B., Car Following Theory of Steady State Traffic Flow, Operations Research 7: 499-505 (1959).
13. Gazis, D. C., Herman, R., Rothery, R. W., Nonlinear Follow the Leader Models of Traffic Flow, Operations Research 9: 545-567 (1961).
14. Gazis, D. C., and Knapp, C. H., On-Line Estimations of Traffic Densities from Time Series of Flow and Speed Data, Transportation Science 5: 283-302 (1971).
15. Grabner, B., A Model for the Calculation of the Optimum Signal Settings, IFAC Transactions, Transportation (June 1972).
16. Grace, M. J. and Potts, R. B., A Theory of the Diffusions of Traffic Platoons, Operations Research 12: 255-275 (1964).
17. Haight, F. A., Mathematical Theories of Traffic Flow, Academic Press (1963).
18. Herman, R., Montroll, E. W., Potts, R. B., and Rothery, R. W., Traffic Dynamics: Analysis of Stability in Car Following, Operations Research 8: 86-106 (1960).
19. Hillier, J. A., and Rothery, R. W., The Synchronization of Traffic Signals for Minimum Delay, Transportation Science 1: 81-94 (1967).
20. Huddart, K. W., and Turner, E. D., Traffic Signal Progressions - GLC Combination Method, Traffic Engineering and Control 11: 320-322, 327 (Nov. 1969).

21. IMSL Library, IMSL Inc., Houston, Texas.
22. Isaksen, L., Suboptimal Control of Large-Scale Systems with Application to Freeway Traffic Regulation, Ph.D. Thesis, University of Southern California (1972).
23. Kaltenbach, M., and Koivo, H. N., Modeling and Control of Urban Traffic Flow, JACC Transactions: 147-154 (June 1974).
24. Knapp, C. H., Traffic Density Estimation for Single and Multi-Lane Traffic, Transportation Science 7: 75-84 (Feb. 1973).
25. Little, J. D. C., The Synchronization of Traffic Signals by Mixed Integer Linear Programming, Operations Research 14: 568-594 (July 1966).
26. Little, J. D. C., Martin, B. V., and Morgan, J. T., Synchronizing Traffic Signals for Maximum Bandwidth, Highway Research Record 118: 21-47 (1960).
27. Messer, C. J., Whitson, R. H., Kuddek, C. L., and Romano, E. J., A Variable Sequence Multi-Phase Progression Optimization Program, Highway Research Record: 24-33 (1972).
28. Miller, S. B. and Little, J. D. C., Evaluation and Improvement of Traffic Signal Settings by Simulation, Highway Research Record 170: 56-69 (1967).
29. Morgan, J. T. and Little, J. D. C., Synchronizing Traffic Signals for Maximum Bandwidth, Operations Research 12: 896-912 (1964).
30. Munjal, P. K., and Hsu, Y. S., Comparative Study of Traffic Control Concepts and Algorithms, Highway Research Board 409: 64-80 (1972).
31. Nahi, N. E. and Trivedi, A. N., Recursive Estimation of Traffic Variables: Section Density and Average Speed, Transportation

- Science 7: 260-286 (Aug. 1973).
32. Newell, G. F., Synchronization of Traffic Lights for High Flow,  
Quarterly of Applied Mathematics 21: 315-322 (1964).
33. Payne, H. J., Thompson, W. A., and Isaksen, L., Design of a Traffic  
Responsive Control System for a Los Angeles Freeway, IEEE Trans-  
actions on Systems, Man and Cybernetics SMC-3: 213-224 (May 1973).
34. Powell, M. J. D., An Efficient Method for Finding the Minimum of a  
Function of Several Variables without Calculating Derivatives,  
Computer Journal 7: 155-162 (1964).
35. Preparada, F. P., Analysis of Traffic Flow on a Signalized One-Way  
Artery, Transportation Science 6: 32-51 (Feb. 1972).
36. Robertson, D. I., TRANSYT Method for Area Traffic Control, Traffic  
Engineering and Control: 276-281 (October 1969).
37. Seddon, P. A., Another Look at Platoon Dispersion, Traffic Engineer-  
ing and Control, 11: 442-444 (February 1972).
38. Singh, M. G. and Tamura, H., Modeling and Hierarchical Optimization  
for Oversaturated Urban Road Traffic Networks, International  
Journal of Control 20: 913-934 (June 1974).
39. Wismer, D. A., Optimization Methods for Large-Scale Systems,  
McGraw-Hill (1971).
40. Yardeni, L. A., Algorithms for Traffic Signal Control, IBM Journal  
4: 143-161 (1970).
41. Zangwill, W. I., Minimizing a Function Without Calculating Deriva-  
tives, Computer Journal 10: 293-296 (1967).